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A New Approach for Measuring the Operational Value of Intelligence for Military Operations

Final Report

Edison Cesar, Patrick Allen, Steven Bankes, John Bondanella, Rick Eden, H. Edward Hall, Clairice Veit, Loretta Verma, Robert Weissler, Barry Wilson

Arroyo Center

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PREFACE

"Measuring the Operational Value of Intelligence, Electronic Warfare, and Target Acquisition (OPVIEW)" was a research project in the RAND Arroyo Center. It was sponsored by the Deputy Chief of Staff for Intelligence, Headquarters, Department of the Army (DA); the Deputy Chief of Staff for Operations, Force Development, Headquarters, DA; and the U.S. Army Intelligence Center, Fort Huachuca, AZ. The project was approved by the Arroyo Center Policy Committee in October 1989. This work was conducted in the Applied Technology Program of the Arroyo Center, directed by Dr. Kenneth Horn.

This report will be of particular interest to those who are involved in policy analysis for the Army's five-year program; in developing and applying methodology and models to assess military value, particularly the value of intelligence; and in comparing the potential contributions of Intelligence and Electronic Warfare/Target Acquisition (IEW/TA) systems, employment doctrine, and technologies in various military operations scenarios.

The purpose of this project was to develop a methodology and one or more prototype models for studying IEW/TA in an operational context; more specifically, the methodology enables the operational value of intelligence assets and activities to be expressed in quantifiable terms useful to resource acquisition decisionmakers, military planners, and operational managers. One application of the methodology is to help build the intelligence portion of the Army five-year program.

The two prototype models were designed as aids for performing policy and other analysis of key issues. The term "prototype" refers to a model that has been developed to the point that its usefulness has been demonstrated. The models can be used to help look for gaps and redundancies in current and proposed capabilities, help justify resource allocations, and seek desired mixes and employment strategies of IEW/TA assets and their communications network architectures to support operations. They were also used as tools for developing the methodology.

The models do not attempt to "certify" the validity of the data used with them. OPVIEW's merits should be judged primarily by the models themselves and the way they organize, present, and help manipulate data (from whatever source) for performing analysis and not by the databases that presently reside in them. Since data are in table form they can be readily changed.

This report is one of many publications describing the Operational Value of Intelligence project:

- E. Cesar, P. Allen, and R. Eden, *Finding a New Approach to Measure the Operational Value of Intelligence for Military Operations: Annotated Briefing*, N-3551-A, 1992. This Note provides an executive-level overview of the OPVIEW project.
- Steven C. Bankes, *Exploratory Modeling and the Use of Simulation for Policy Analysis*, N-3093-A, 1992. This Note documents insights into the use of simulation modeling for difficult policy problems.
- Steven C. Bankes, *Methodological Considerations in Using Simulation to Assess the Combat Value of Intelligence and Electronic Warfare*, N-3101-A, 1991. This Note describes issues that must be addressed if the contributions of IEW/TA systems to operational outcomes are to be reliably assessed through the use of simulation models.
- J. R. Bondanella et al., *Estimating the Army's Intelligence Requirements and Capabilities for 1997–2001: Analytic Support to the Military Intelligence Relook Task Force*, MR-228-A, 1993. This report documents analytic support of the Army's "MI [Military Intelligence] 2000 Relook" study effort and reports the results of analysis employing the OPVIEW methodology to assess the capabilities of intelligence organizations, processes, and systems for performing as an integral component of AirLand operations for contingencies in multiple regions.
- E. M. Cesar, Jr., et al., *Preliminary Assessments for Employing Selected Army Pacing IEW Systems in Central Europe*, N-3061-A (classified publication, not available for public release), August 1990. This Note describes a particular application of the OPVIEW methodology at corps and division command levels in a Central European setting.

Throughout this project, the research team met with key members and elements of the Army's methodology and model development community and presented briefings and demonstrations. These audiences included representatives from the offices of the Deputy Under Secretary of the Army (Operations Research), the Deputy Chief of Staff for Operations and Plans, the Deputy Chief of Staff for Intelligence, the U.S. Army Intelligence Center, the Training and Doctrine Command, the Combined Arms Command, the Intelligence and Security Command, the Army Materiel Systems Analysis Agency, the TRADOC Research and Analysis Center, the U.S. Army Intelligence Agency, the Joint Tactical Fusion Office, LABCOM, the Army Research Office, and the Air Defense Artillery Center and School.

THE ARROYO CENTER

The Arroyo Center is the U.S. Army's federally funded research and development center (FFRDC) for studies and analysis operated by RAND. The Arroyo Center provides the Army with objective, independent analytic research on major policy and organizational concerns, emphasizing mid- and long-term problems. Its research is carried out in four programs: Strategy and Doctrine, Force Development and Technology, Military Logistics, and Manpower and Training.

Army Regulation 5-21 contains basic policy for the conduct of the Arroyo Center. The Army provides continuing guidance and oversight through the Arroyo Center Policy Committee (ACPC), which is co-chaired by the Vice Chief of Staff and by the

Assistant Secretary for Research, Development, and Acquisition. Arroyo Center work is performed under contract MDA903-91-C-0006.

The Arroyo Center is housed in RAND's Army Research Division. RAND is a private, nonprofit institution that conducts analytic research on a wide range of public policy matters affecting the nation's security and welfare.

James T. Quinlivan is Vice President for the Army Research Division and Director of the Arroyo Center. Those interested in further information about the Arroyo Center should contact his office directly:

James T. Quinlivan
RAND
1700 Main Street
P.O. Box 2138
Santa Monica, CA 90407-2138

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BACKGROUND AND OBJECTIVES

Many government agencies—including the Congress, the Department of Defense (DoD), and the Services—are charged with formulating policy for developing requirements and providing resources and force structure for military intelligence. Each agency faces difficulties in selecting policies and programs and in predicting the consequent effects of their selections on military effectiveness. Typically, military budgets are developed within an intelligence discipline, such as signals intelligence, imagery intelligence, or human intelligence. When reductions are necessary, each discipline normally takes a "fair share" cut. Such an approach, however, assumes that the balance among disciplines and systems is constant regardless of changes exogenous to the intelligence community. A methodology was needed to measure the value of intelligence that is credible to *all* users.

The Army requested that the Arroyo Center develop such a methodology in its project on measuring the operational value of intelligence, electronic warfare, and target acquisition (IEW/TA) (OPVIEW). The overarching goal was to enable analysts to rapidly examine numerous cases, thus providing decisionmakers with tradeoffs, over time, between competing IEW/TA systems and capabilities. By forging a closer link to operational and doctrinal changes in military operations, the methodology was to provide decisionmakers with a better analytic basis for making balanced multiyear investment decisions.

APPROACH

A key challenge in meeting these objectives was to represent the intelligence process in a simulation model that can relate IEW/TA system results to decisionmaking and resultant operational outcomes. Including IEW/TA in simulations significantly increases the uncertainty that must be addressed. Because it deals with "soft" or psychological factors (e.g., the decision process of individual commanders), small changes in IEW/TA can produce large changes in outcome. For example, in situations involving overwhelming force ratios, the operational value of intelligence may be negligible, but in some situations, a single command decision can mean the difference between victory and defeat.

Because the concerns of policymakers cannot be predictively modeled, the study evaluated and recommended exploratory modeling, where the analyst employs a strategy of searching for the most important cases and of using human judgment to

prioritize his investigation of the uncertainties. Although detailed prediction of outcomes may not always be possible, the analyst can gain important insights about the problem through systematic exploration. Such a methodology has the following features:

- *Aggregated modeling*, which limits both the number of uncertainties and the time for individual runs;
- *Question-driven modeling*, which provides focus that limits irrelevant factors;
- *Analytic strategies*, which provide a top-down structuring of the cases to be run;
- *Selective variability of model resolution (neither all high nor all low)*, which allows for structuring the search of the universe of cases and for optimizing the use of analytic resources; and
- *Transparent modeling aided by English-like computer code and graphic illustrations of the unfolding operational setting*, which allows for rapid model revision.

THE ANALYTIC PROCESS

This project developed an analytic process that enables analysts to narrow the search for a preferred mix of IEW/TA assets within a set of proposed mixes. This requires more than simply examining the output of a fixed-function model—it requires combining simulation and nonsimulation techniques to arrive at preferred and minimum acceptable system mixes. Those mixes are then analyzed for other criteria outside the military operations environment (e.g., economic production programs, force structure, or personnel constraints) *to arrive at the recommended priorities.* The process involves the following steps.

1. Select potential region or theater of operations.
2. Identify U.S. and opponent's regional objectives.
3. Select strategies.
4. Specify missions and operational phases.
5. Develop campaign plans to execute missions, including the postulated allocation of threat and friendly forces.
6. List intelligence information requirements, including desired reporting time limits.
7. Evaluate proposed and programmed IEW/TA mixes (selecting from a number of alternative methodologies, including static and dynamic models developed by this project and described below) to match IEW/TA capabilities for each region and mission.
8. Perform additional analysis where the models and simulations do not sufficiently discriminate between the IEW/TA inputs and operational outcomes.
9. Examine results for dominance of IEW/TA system types, or lack thereof.
10. Recommend dominant or tailored mixes for the force (retain, acquire, or develop).

11. Perform a value-scoring analysis for input to the Planning, Programming, Budgeting, and Execution System (PPBES)[1] process, with supporting rationale derived from qualitative analysis.

PRODUCTS OF THE STUDY

In addition to the overall analytic framework outlined above, this project produced three analytic tools, as well as analytic results derived from applying the models. The first is an aggregate-level methodology for measuring the performance (i.e., resolution and timeliness) of intelligence systems in terms that relate to the information needs of a commander. The second is a static or time-independent model for applying the measurement methodology to a wide range of conflict regions and conflict states. The third is a dynamic or time-dependent simulation model for applying the measurement methodology to selected conflict regions and conflict states.

Aggregate-Level Measurement Methodology

The value of military intelligence is always a function of the operational situation.[2] Therefore, one cannot ascribe a single *a priori* value to a given sensor or intelligence asset unless one first examines the performance of the assets in a wide range of situations.

The aggregate-level methodology was designed to reflect the ability of a given type of sensor to support the commander's information needs in a given situation. For each type of collection means, the following standard collection requirements and matching system capabilities were defined:

1. Detect;
2. Locate generally;
3. Locate precisely;
4. Classify;
5. Identify;
6. Track;
7. Acquire;
8. Assess postattack operational status of one or more threat entities (including battle damage assessment).

For each intelligence requirement, the desired rates of detection, location, and so on are specified (i.e., when the commander needs the information, the capacity or rate of each sensor that is employed to obtain it, plus the production system to produce and disseminate it).

[1]The other services use the Planning, Programming, and Budgeting System (PPBS).

[2]In this report, the *value* of intelligence does not pertain to the intrinsic value of intelligence to a particular operation, which must always be scenario-dependent, but rather, to the *kind* of intelligence that is provided by various collection capabilities and its potential effect on decisionmaking and other actions by a commander derived from a number of scenarios. We are indebted to our RAND colleague, Glenn Kent, for helping us clarify this distinction.

Each type of sensor will contribute to each of these tasks in a different manner that will vary as a function of the situation. Similarly, the commander will use his sensors to accomplish these tasks after considering specific conflict situations. Note that the commander does not need to know every bit of information about every enemy unit. For example, if he needs to know whether enemy forces are present along a given avenue of approach, he may need only to *detect* and *generally locate* the enemy forces. If, instead, he needs to know where the enemy's armored units are, he may need to *classify* the units. If he needs to know if the enemy has already committed his reserves, he may need to *identify* the units. If he wishes to target and attack specific units, he must *track* and *acquire* the targets. If he needs to know whether a given unit is still combat effective, he will need to *assess its operational status.*

With the OPVIEW methodology, the analyst can assign each type of intelligence system a score indicating its potential capability, operational and environmental constraints aside, to perform any one or combination of the eight intelligence functions listed above. We call this score the collection probability factor, or CPF. A CPF is expressed as a numerical value between 0 and 1, where 0 indicates no possibility of performing a specified function and 1 indicates a certainty of performing the function. CPFs represent the full technical potential capability of a system to perform a specific intelligence function; they are ideal scores that must be discounted in specific scenarios to reflect the way in which operational and environmental factors can be expected to degrade the performance of the system.

For this reason, we developed an adjusted score called conditional collection probability factors (CCPFs). CCPFs are defined as CPFs modified to reflect the environmental and operational conditions affecting the performance of a collection system in a given region. The environmental and operational factors considered in developing the CCPFs included topography, weather, and passive and active countermeasures. Like the CPF, the CCPF is expressed as a probability value ranging from 0 to 1. CCPFs can be used to define collection system coverage results and information timeliness for a single IEW/TA system or any mix of collection capabilities.

The OPVIEW aggregate-level measurement methodology may be used in conjunction with a variety of analytic tools to assess the value of intelligence in specific scenarios. Two such tools were produced by this project and are described below.

Static Analysis Model

The static (or time-independent) model is a spreadsheet tool that emphasizes analytic breadth covering a wide range of regions and conflict states, but with little detail; for this reason, it can also be used as a screening tool to identify cases that merit a more detailed analysis using the dynamic model.

The static model is a Microsoft Excel spreadsheet program which runs on a Macintosh computer. The model was used to support the Army's Military Intelligence (MI) Relook study. For this study, the model was used to examine a set of scenarios consisting of eleven combinations of conflict regions and conflict states. The combat scenarios included warfighting scenarios at the theater and corps operational levels. The noncombat scenarios included peacekeeping missions, noncombatant evacuation operations, and low-intensity conflicts. Each scenario included a variety of terrain, weather, and countermeasure effects. The countermeasures included camouflage and electronic mission control and such active measures

as smoke and jamming. Because of the static nature of the tool, the terrain, weather, and countermeasure effects were combined into degradation factors affecting the ability of each type of sensor to perform the intelligence tasks listed above.

Each scenario also included between one and four operational phases that represented likely submissions during a particular operation in the scenario. For example, the information requirements during the indications and warning phase tend to be different from those during campaign planning and conflict execution phases. The static tool was employed to discount the value of certain intelligence tasks depending on the phase of each mission. For example, targeting is not usually a task associated with a peacekeeping mission in noncombat scenarios, or with the indications and warning phase of combat scenarios. Discount factors were also applied to each of the tasks performed by each collection platform.

For each mission and average situation, the analyst provides, as input to the model, preferred and minimum essential packages of collection and production assets to accomplish the mission, and the model is used to present and compare the outputs. Any synergism between assets, such as cross-cueing unmanned aerial vehicles (UAVs) by the Joint Surveillance and Target Attack Radar System (JSTARS), was assumed to be accounted for in the package definition. In addition, further discount factors were defined for the responsiveness of the platform and the timeliness of the information provided by the platform. For example, campaign planning and campaign execution phases tend to require faster feedback than does reconstitution. Discount factors were included by type sensor to reflect the effects of delays in intelligence production and dissemination when time-sensitive operations were involved. System responsiveness was represented by similar factors to account for possible lack of Army priority when non-Army sensors are tasked to support Army operations.

The end result was a value assigned to each type of sensor to perform a specific task that reflects the general (i.e., static) situation in a theater of operations. The project's support to the MI 2000 Relook study is described in more detail below.

Dynamic Analysis Model

The dynamic (or time-dependent) analysis model was designed to be narrower in scope but greater in detail. Its main emphasis is to reflect the dynamic interactions between the commander's decisions about his current plan, the sensors he employs, and their ability to support the current plan as it unfolds (or unravels, as the case may be) as well as the relationship between the results of collection, changes to plans, and operational outcomes that result from plan changes. The dynamic model has been developed as a prototype.

The dynamic model requires much more detailed inputs than the static tool, including a map of the terrain, the forces available to each side, the mission and plan of each side to accomplish its objectives, and the sensor allocation scheme to support the plan. Unlike the static tool that defines an average situation, the dynamic model simulates the ability of a sensor to accomplish a given intelligence task in a specific type of terrain and visibility and against specific countermeasures that may be employed by enemy units. Sensor assets may be attrited in a deterministic (fraction of capability that may have been lost as a result of cumulative risk) or stochastic (lost or

survived as a result of a computer's pseudorandom number generator) manner, depending upon the analytic requirements.

In addition to the terrain map (which is overlayed), the dynamic model also displays a "coverage" map, which indicates the degree of detection coverage currently available in a given 10 × 10 km grid. Assets that cover less than this in a one-hour time step contribute a proportional fraction of their full coverage in that smaller area. As sensor assets move, the coverage maps automatically change. Visibility factors degrade coverage, depending upon the type of asset.

The degree of coverage by intelligence task is stored for each unit (both friendly and enemy). The ability to gather information on a unit depends on its passive or active countermeasures and the degree of coverage for each intelligence task. For example, a stationary unit will not be detected by JSTARS, and if it has employed camouflage or smoke, the ability of IMINT sensors to detect it by visual frequencies band will be reduced. If there is sufficient information in each intelligence task category, the enemy unit may be perceived by the friendly side in various levels of detail: undetected; detected, with only the size known; detected, with type of unit known; and detected, with identity of the unit known.

If an enemy unit is in a target area of interest (TAI), it may be engaged by friendly fire support assets only if the coverage of the TAI is current and sufficient for acquiring targets. The greater the acquisition coverage, the higher the number of assets in the TAI that may be attacked. Similarly, the greater the ability to currently perform operational status assessment (or poststrike battle damage assessment), the greater the ability to report the actual number of enemy assets destroyed in the attack.

There are two representations of information timeliness in the models. The aggregate representation of timeliness used in the static model employs discount factors to reflect that assets with real-time collection capabilities are very useful for targeting, whereas assets with near-real-time collection capabilities are slightly degraded, and longer-time collection capabilities are significantly degraded for tracking and targeting tasks.

For the dynamic model, more explicit representation of timeliness tracks intelligence data over time so that the effects of timeliness may be analyzed in more detail; this also allows intelligence inferences and deception to be represented. For example, if an enemy unit is stationary, no other similar units are in the area, and the unit was identified within the last hour, then by inference, the identity of the enemy unit should be known in this hour as well, even if only the presence of the stationary unit was detected. Although this process is not yet active in the current dynamic prototype model because of the large memory and computation time requirements, it can be added by employing linked lists rather than only the array data structures that are presently in place.[3]

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[3]A linked list is a list of items constructed by having each item in the list indicate which item is next. This arrangement allows items to be easily inserted or removed from any place on the list and allows the list to be extended to arbitrary lengths.

Both the OPVIEW methodology and the two models depend fundamentally on subjective judgment data. In our analyses these data were developed systematically using basic physical laws and the performance characteristics of IEW system modified by experts in operations planning, intelligence collection, and production analysis.

AN APPLICATION OF THE METHODOLOGY—THE MI 2000 RELOOK STUDY

Military intelligence is being driven to take on new roles, both doctrinally and operationally. For example, Battle Damage Assessment (BDA) and collection and analysis of postattack enemy residual operational capability information are as important to the Air Force and the Navy as to the Army. For *noncombat* operations (e.g., noncombatant evacuation operations (NEO), peacemaking and peacekeeping operations, disaster relief, and drug interdiction), military intelligence must be able to assume such additional roles as maintaining an overall view of affected areas and delineating hot spots where there may be little or no readily discernible differences between friendly and hostile entities or activities. In such operations, the fast pace of unfolding crises, combined with the low density of threat entities in some regions, implies that intelligence assets must be more precise, more timely (or more patient), and more capable of discriminating threat entities than at any time envisioned in the past for conventional conflicts. And military intelligence will need to do all this within the constraints of declining DoD resources, which requires improved methods and tools for analysis.

Despite the uncertainties, some prudent analysis can be performed to determine how intelligence units, equipment, and procedures might be organized to minimize the potential risk imposed by adverse environments. The Army chartered the Military Intelligence (MI) 2000 Relook Task Force to conduct such an analysis from June through September 1991. The initial findings of the task force had to do with supporting the Military Intelligence General Officer Steering Group for Total Army Analysis 1999, with more substantive findings related to developing the Army's Program Objectives Memorandum for fiscal years 1994–1999 and the Army Long-Range Acquisition and Modernization Requirements Plan for fiscal years 1994–2008.

The Arroyo Center was asked to assist the task force by applying the OPVIEW methodology. This was the second time the project team had the opportunity to apply the methodology in an actual study; the developmental methodology had already been tested in a special assistance study for the Army Deputy Chief of Staff for Intelligence in 1989 in formulating the *Fiscal Year 1991 Army Budget* and the *Fiscal Year 1992–1997 Army Program Objectives Memorandum.*

We believed that a multiscenario approach would provide a robust environment to evaluate IEW/TA systems that could be critical to military operations in uncertain circumstances over the next 10–15 years. Consequently, we generated eleven scenarios, comprising twenty-eight missions in seven regions—Eastern Europe, the Persian Gulf, Israel, Korea, Honduras, the Philippines, and Pakistan. Included in this list is an NBC (Nuclear/Biological/Chemical) crisis response case, in which we postulated that the United Nations would form a reaction force to intervene in crises and forestall the use of NBC weapons by the belligerents. The eleven scenarios are listed below:

Combat	Noncombat
Honduras	Honduras
Israel-Syria	Israel and Persian Gulf
North-South Korea	North-South Korea
Eastern Europe, Poland-Russia	Philippines
NBC Crisis Response	Pakistan-India
Southwest Asia, Saudi Arabia	

We developed a factor (CPF) to represent IEW/TA system performance in an ideal, benign environment and modified that factor (CCPF) for each IEW/TA system to account for the operational effect of terrain, weather, mission criticality, and potential enemy countermeasures for each scenario/region. We considered four operational phases to be important, depending on the scenario: indications and warning, crisis management, campaign planning and conflict execution, and reconstitution.

We examined systems in the current inventory and those that may be fielded within ten years, including Army, Air Force, and national collection assets. Among the newly fielded or developmental systems are the radar imaging systems on aerial platforms, which have an all-weather capability against moving or fixed targets (JSTARS; Advanced Synthetic Aperture Radar System—ASARS); the family of common-sensor signals intelligence systems on aerial platforms (GUARDRAIL—fixed wing; Advanced Quick Fix—helicopter) and on ground platforms (heavy and lightweight Ground-Based Common Sensor (GBCS) system); and the imaging systems on UAVs. Further, we did not limit our analysis to technical performance parameters but also examined the system connectivity architectures that are so vital in processing, analyzing, and disseminating intelligence to commanders within the time required to take effective action.

Using the static model, we derived an approximation of results that one might obtain with the more complex dynamic simulation. The process yielded insights concerning the strengths and weaknesses of the varying IEW/TA systems; however, it did not represent operational outcomes. We believe this simpler process still shows that although any given system may dominate other systems in a particular task, a mix of complementary systems over the variety of tasks in multiple scenarios provides the balance needed by military commanders. Therefore, by inference, the preferred mixes ought to result in better operational outcomes if they are evaluated in a dynamic simulation.

The multiscenario assessment shows that the tactical airborne radar imaging systems (JSTARS for moving targets and ASARS for stationary targets) are extremely valuable in scenarios characterized by large-scale military conflict (Europe/SWA) and for the NBC crisis response mission, where large, denied areas need to be covered rapidly and comprehensively under the most adverse environmental conditions. The other systems operate in a highly complementary fashion, as evidenced by the close range of values across combat and noncombat scenarios. For example, although in one case JSTARS and ASARS are valued higher individually, their values were achieved within a particular mix of other IEW/TA systems where commanders required the other systems to do more precise planning and execution, continuously for all four missions.

We observed across a wide variety of scenarios that there is an almost equal value-added score for each IEW/TA system in the preferred mixes we examined. This does not represent redundancy or duplication; rather, it highlights the fact that each system was better suited to overcome some particular aspect of the environment (e.g., weather, terrain, and potential enemy countermeasures) or timeliness in performing and reporting specific tasks (e.g., detect, locate, and identify) required to successfully accomplish different missions.

We concluded that the balance among current IEW/TA systems was sufficient for the 1980s, when a more linear battlefield was expected, but that there needs to be a different balance among the intelligence functional areas to perform successfully as an integral component of AirLand operations, which are expected to be more dynamic and nonlinear in the future.

PROJECT STATUS

The OPVIEW project ended in 1992 after four years of research. In that time it developed the OPVIEW methodology, a static model, and a prototype dynamic model. The static model was transferred to the Army with the final report of the effort in support of the MI 2000 Relook study. The prototype dynamic model—which demonstrates the proof of principle but is not yet a production model—was transferred to the Army with this report.

Although the prototype model has been demonstrated to connect, end-to-end, all of the submodels and provide results for analysis, it is not yet sufficiently robust to perform extensive sensitivity analysis. When the model is to be used to support studies, scenarios, operational plans, doctrine, rules, and environmental and system-appropriate data will have to be added.

FUTURE USES FOR THE METHODOLOGY

The OPVIEW methodology, which we envision being used at the Army Staff, INSCOM, and the U.S. Army Intelligence Center, should prove useful to other government intelligence agencies as well. It provides a disciplined approach to making the necessary resource allocation decisions in a manner that is not parochial. When combined with analysis of economic production, manpower programs, and the total military force to be supported, the methodology could provide acquisition managers and decisionmakers with a clear, substantive basis for structuring and enunciating the benefits of their programs for the DoD Program Objectives Memorandum and for the Presidential Budget submission to Congress.

Another potential use for the OPVIEW methodology and models would be to produce a continually updated database for intelligence (and other information) collection and production capabilities and their measured effectiveness under a variety of conditions. The product would be similar to the *Joint Munitions Effectiveness Manual (JMEM).*

ACKNOWLEDGMENTS

A number of individuals helped make this project successful, both in the Army and at RAND. The key people, besides the OPVIEW team members, are mentioned here.

James D. Davis, the Deputy Assistant Chief of Staff for Intelligence (DCSINT) (Management), was the primary sponsor for this project. He, along with Lieutenant General Sidney T. Weinstein, the DCSINT at the time, correctly saw the need to be able to measure the value of intelligence at the operational level and contributed much insight about previous attempts that had proved unsuccessful and the reasons.

MAJ Lester F. McConville was one of the first DCSINT Action Officers. He helped us obtain essential research materials during the early phase of the project.

COL Edward Gore performed admirably as the DCSINT Action Officer for the project during its most formative stage. He arranged important briefings and helped obtain essential data for the model's tables. He directly participated in one of the two special studies to apply the OPVIEW methodology in an actual case study.

LTC James Waite served as the DCSINT Action Officer during the last year of the project. He assisted greatly by arranging to review our Working Drafts and performing a number of important coordination tasks with members of the Army Staff.

MAJ Keith Marass performed as the DCSOPS Action Officer for this project.

Michael Powell, assigned to the Combat Developments Directorate at USAIC, Fort Huachuca, AZ, was involved in model development on the IEW Functional Area Model (FAM). He provided several substantive briefings on the status of the FAM model and helped critique the OPVIEW approach.

Woodson Tucker, assigned to the Combat Developments Directorate at USAIC, Fort Huachuca, AZ, was also involved in model development work on the IEW Functional Area Model. He also helped critique the OPVIEW approach.

William Clay, of AMSAA, Aberdeen, MD, contributed sensor performance data for some of the model's tables.

LTC Lance Tomei, an Air Force officer serving in an Army billet, was the first person outside of RAND to use the fledging model (specifically, to analyze unmanned aerial vehicles). He provided helpful insights from a very knowledgeable intelligence officer's user perspective.

LTC Michael J. Diver, a RAND Army Fellow, served as the first Army intelligence officer assigned by the DCSINT to work with the OPVIEW team. He made important

contributions to the development of the sensor and intelligence submodels, and guided much of the team's work by being the resident Army subject matter expert.

LTC William Knarr, also a RAND Army Fellow, served as the second and last intelligence officer assigned to the project. He developed the Southwest Asia scenario in its entirety and helped to integrate it into the model. This scenario was used in the second game trial. He also gave the team valuable insights from a subject matter expert's viewpoint concerning military operations in general, and more specifically, from an intelligence operator's perspective on IEW/TA systems and employment doctrine. His views were enormously valuable for guiding the team's efforts at crucial phases during both the methodology's and prototype model's development work.

As the first Director of the Arroyo Center, Stephen Drezner realized the importance of the Army's being able to measure the value of intelligence and agreed to undertake the study, notwithstanding that at the time the project was approved by the Arroyo Center Policy Committee (ACPC), it was considered to be a high-risk endeavor. He was a key supporter and frequent mentor of the methodological approach during the project's formative stages. One key guiding factor was to carefully develop the methodology, giving greater attention to it in the beginning than to the model development work.

Marlin Kroger, a RAND consultant, gave unstintingly of his ideas and helped shape the project's direction during its early phase. Unfortunately, as a result of his untimely death, he was unable to continue with the project to its end; however, he made valuable contributions to the conceptual aspects of the methodology and his imprint on the project endured to its end.

Jefferson Marquis, a research assistant during the early stages of the project, helped organize and analyze categories for the measures of performance and measures of effectiveness of IEW/TA systems.

Phillip Propper helped write several combat scenarios for the Arroyo Center's study in support of the Army's MI Relook Study. He also did much of the work of entering and manipulating data for the value-added scoring process for the eleven scenarios developed for this phase of the work.

Together, Calvin Shipbaugh and Daniel Gonzales researched Army, Air Force, and Navy IEW/TA system descriptions and their characteristics.

John Clark gave OPVIEW briefings and served as the alternate Project Leader for a period of six months.

Together, William Schwabe and Richard Hillestadt performed a highly beneficial critique of the OPVIEW methodology and dynamic model at an important time in their development.

William Schwabe and Leland Joe provided insightful and comprehensive reviews of this final report.

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ACRONYMS

ACPC	Arroyo Center Policy Committee
AD	Air Defense
ADA	Air Defense Artillery
AIA	U.S. Army Intelligence Agency
AIMP	Army Intelligence, Electronic Warfare, and Target Acquisition Master Plan
AMC (PEO-IEW)	Army Materiel Command (Program Executive Office for Intelligence and Electronic Warfare)
AMSAA	U.S. Army Materiel Systems Analysis Activity
APC	Armored Personnel Carrier
AQF	Advanced QUICK FIX
ASARS	Advanced Synthetic Aperture Radar System
BDA	Battle Damage Assessment
CCPF	Conditional Collection Probability Factor
CI	Counterintelligence
COEA	Cost and Operational Effectiveness Analysis
COMINT	Communications Intelligence
CPF	Collection Probability Factor
DA	Department of the Army
DCSINT	Deputy Chief of Staff for Intelligence
DCSOPS	Deputy Chief of Staff for Operations and Plans
DLR	Defender Loss Rate
DOC EX	Document Exploitation
DoD	Department of Defense
EAC	Echelons Above Corps
ECCM	Electronic Counter-Countermeasures
ED	Equivalent Divisions
ELINT	Electronic Intelligence
EMCON	Emission Control
ER	Exchange Rate
ESM	Electronic Warfare Support Measure
FAM	Functional Area Model
FEBA	Forward Edge of the Battle Area
FFRDC	Federally Funded Research and Development Center
FIM	Functional Integration Model
FLOT	Forward Line of Own Troops
FMR	FLOT Movement Rate
FORSCOM	Forces Command
FSE	Fire Support Element

G2	Intelligence Staff Office
G3	Operations Staff Office
GBCS	Ground-Based Common Sensor
GBCS(H)	Ground-Based Common Sensor (heavy division)
GBCS(L)	Ground-Based Common Sensor (light division)
GRCS	GUARDRAIL Common Sensor
HPT	High-Priority Target
HQs	Headquarters
HUMINT	Human Intelligence
ID	Identification
I&W	Indications and Warning
IEW/TA	Intelligence, Electronic Warfare, and Target Acquisition
IMINT	Imagery Intelligence
INSCOM	Intelligence and Security Command
"INT"	An unofficial term for generic intelligence discipline (e.g., HUMINT); also used in this report as the title for the interpreter directory of the dynamic submodel
IPB	Intelligence Preparation of the Battlefield
IPDC	Intelligence Production and Dissemination Center
IPW	Interrogation of Prisoners of War
IR	Information Requirements
IR	Infrared
JIEM	*Joint Information Effectiveness Manual*
JMEM	*Joint Munitions Effectiveness Manual*
JSTARS	Joint Surveillance and Target Acquisition Radar System
LIC	Low-Intensity Conflict
LLLTV	Low Light Level Television
MAA	Mission Area Analysis
MAPVIEW	An X-based graphics tool, developed at RAND, for illustrating simulated objects overlayed on a background of terrain features
MASINT	Measurements and Signatures Intelligence
MENS	Mission Essential Needs Statement
METT-T	Mission, Enemy, Terrain, Troops Available-Time
MI	Military Intelligence
MLRS	Multiple Launch Rocket System
MOE	Measure of Effectiveness
MOP	Measure of Performance
MOR	Measure of Results
MOSF	Military Operations Simulation Facility (at RAND)
MOU	Measure of Utility
MOV	Measure of Value
MRL	Multiple Rocket Launcher
MRLS	Multiple Rocket Launcher System
MTI	Moving Target Indicator
NAI	Named Area of Interest
NATO	North Atlantic Treaty Organization
NBC	Nuclear/Biological/Chemical
NEO	Noncombatant Evacuation Operations
NLC	Nonlinear Combat (model)
NLOS	Non-Line of Sight

NRT	Near Real Time
OMG	Operational Maneuver Group
OPLAN	Operational Plan
OPSEC	Operations Security
ORD	Operational Requirement Document
OPVIEW	Operational Value of Intelligence and Electronic Warfare
PIR	Prioritized Intelligence Requirement
POSNAV	Position Navigation
PPBES	Planning, Programming, Budgeting, and Execution System
RAMP	RAND Analytic Modeling Platform
RAND-ABEL	Computer simulation language developed at RAND
RAND-ANABEL	Computer simulation language developed at RAND
RSAC	RAND Strategy Assessment Center
RSAS	RAND Strategy Assessment System
SAR	Synthetic Aperture Radar
SD	Situation Development
SIGINT	Signals Intelligence
SSP	Single Source Processor
STF	Subjective Transfer Function
SWA	Southwest Asia
TA	Target Acquisition
TAA	Total Army Analysis
TACREP	Tactical Intelligence Report
TAI	Target Area of Interest
TD	Target Development
TECHINT	Technical Intelligence
TRADOC	Training and Doctrine Command
TV	Television
UAV	Unmanned Aerial Vehicle
UAV-CR	Unmanned Aerial Vehicle-Close Range
UAV-E	Unmanned Aerial Vehicle-Endurance
UAV-SR	Unmanned Aerial Vehicle-Short Range
USAIC	U.S. Army Intelligence Center
USAICS	U.S. Army Intelligence Center and School
V and V	Verification and Validation
V, V, and A	Verification, Validation, and Accreditation

Chapter One

INTRODUCTION

POLICY ISSUES IN MILITARY INTELLIGENCE

Military intelligence is a critical defense function in peace, crisis, and war. It plays a key role in helping our nation to anticipate and avoid future conflicts, respond quickly and appropriately in contingencies, and shape the outcome of operations. Several government agencies are charged with formulating policy for developing requirements and providing resources for military intelligence, including the Congress, the Department of Defense, the Service Secretaries, and the major commands. In the Army, the list of those included in military intelligence policymaking includes the Army Staff, DCSOPS, DCSINT, TRADOC, AMC, INSCOM, and the USAIC. Each of these agencies and commands faces difficulties in deciding which policies and programs to pursue and in predicting the consequent effects on military capability. In the current environment, when defense resources are declining substantially and when major threats are being redefined, decisions regarding military intelligence have become much more complex. Moreover, these decisions must take into account not only reductions in resources but also developments in doctrine and in force structure, such as AirLand operations, contingency deployments, force sizing (reductions and increases) and transitions, and forward defense force projections.

As various defense functions compete for dwindling resources, important decisions must now be made regarding tradeoffs among intelligence capabilities. Agencies responsible for intelligence functions can expect the DoD and Congress to require justifications for their resource requests that are much more cogent and compelling than in the past. Because of the way the Services approach programming and budgeting, it is just as important to be able to measure the value—in operational terms—that may be *subtracted* from one functional area, employing a standard scale for measurement, as it is to quantify and assess the value that may be *added* to another area.

EFFORTS TO PROVIDE ANALYTIC SUPPORT TO MI POLICYMAKING

Military intelligence policymaking should be based on robust analyses conducted with the best available analytic tools. Presumably, high-quality analyses will contribute to a sound foundation for consensus regarding the nation's military intelligence requirements. Moreover, the analyses must be able to measure the value of intelligence in military operations terms that permit comparisons with the value added from other assets and activities.

In the past ten years, there has been marked progress in the development of methodologies and models to provide analytic support to military intelligence policymaking. As Figure 1.1 shows, this progress has evolved in stages representing three "generations" of capability. The direction and character of these developments have been driven in part by the specific policy issues that the methodologies have been designed to address and in part by the availability of new technologies with which to build analytic tools. These technologies include computer hardware, software, languages, and graphics, and their application for conducting realistic wargames and other simulations. These advances enable vast amounts of data to be stored and manipulated and information to be organized and arrayed in many different ways too complex, tedious, and time-consuming for humans.

In 1988, RAND was asked by the U.S. Army Deputy Chief of Staff for Intelligence (DCSINT) to provide analytic support to the Army Intelligence, Electronic Warfare, and Target Acquisition Master Plan (AIMP). This study made several methodological advances to the assessment of military intelligence, including the development of a methodology, with illustrative examples, for choosing and making tradeoffs among competing candidate IEW/TA systems and supporting technologies (Cesar et al., 1988). Nevertheless, during the course of the AIMP study, Army and RAND participants recognized the need for a disciplined approach to measuring the value of intelligence (1) using a common scale and standard units, and (2) in a way that is repeatable and credible to all users. The desire to build toward such a capability led to the initiation of a follow-on project, reported on here: "Measuring the Operational Value of Intelligence (OPVIEW)." Before the OPVIEW methodology was conceptualized and evolved, the Army had no satisfactory standard way to analyze military intelligence policy issues related to collection systems acquisition, intelligence doctrine and its employment, collection system employment strategies (including single system and package employment), and aggregated effects of technology applications.[1]

THE RESEARCH CHALLENGE

Measuring the operational value of intelligence and intelligence systems presented a number of challenges that proved too daunting for the technologies and analytic techniques that were available at the time. At a broad conceptual level, four fundamental challenges had to be overcome.

- How to quantify the performance of intelligence-collection systems (using a standard scale) so they can be analyzed.
- How to relate intelligence to operational planning and execution (i.e., how to represent credibly the way in which collected intelligence influences the decisionmaking of a commander).
- How to adjudicate the outcomes of operations to represent how a commander's decisions, influenced by intelligence, affect mission accomplishment.

[1]The project was approved by the Arroyo Center Policy Committee (ACPC) in October 1989. An agreement was reached on July 7, 1988, between Stephen M. Drezner, Vice President for the Army Research Division, and James D. Davis, Special Assistant to the DCSINT, for RAND to conduct a preliminary exploratory development project to understand the nature of the research issues.

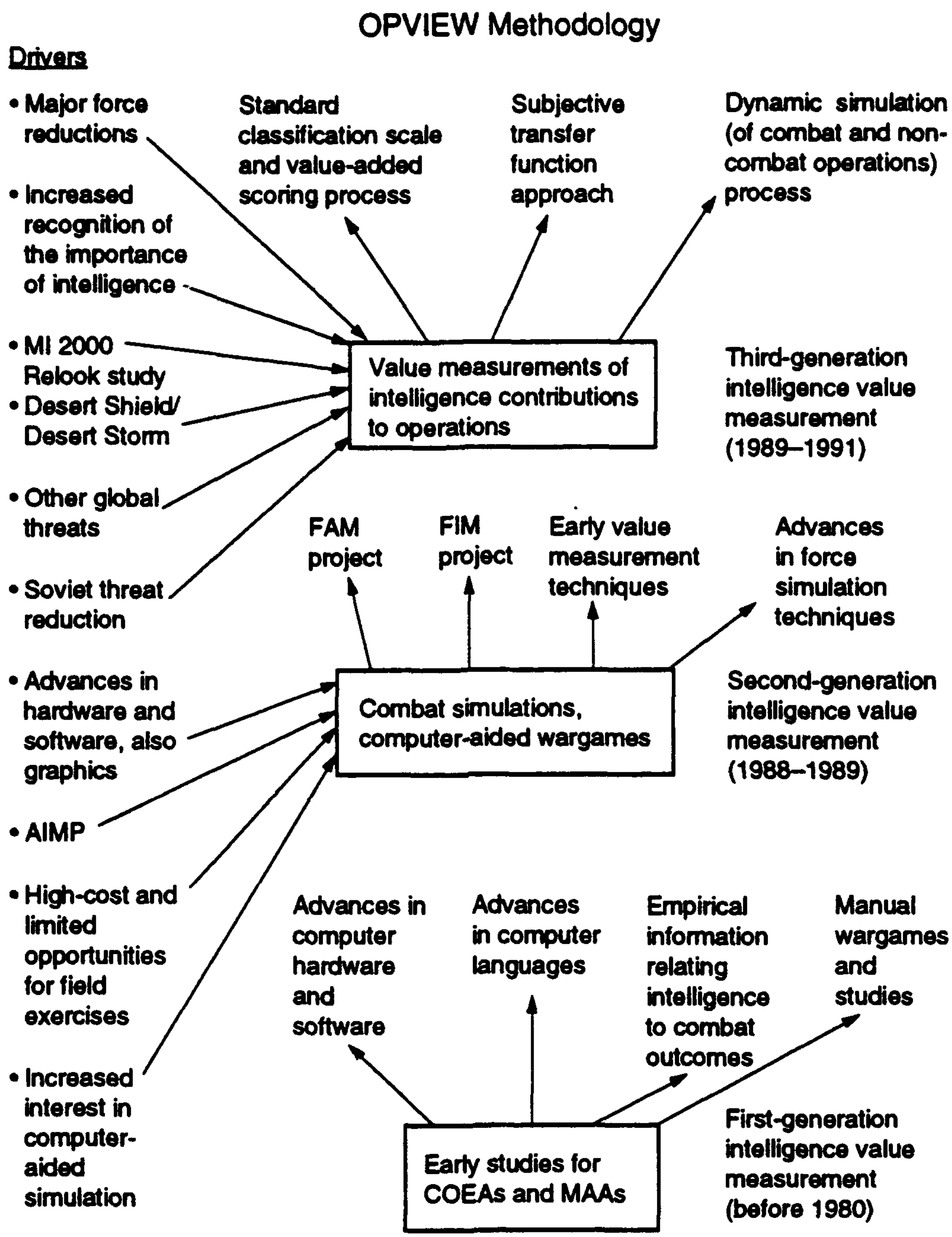

Figure 1.1—Three Generations of Intelligence Value Measurements and the Main Thrusts of Development

- How to synthesize and summarize the results of many scenarios to arrive at a robust assessment of the operational value of intelligence.

The OPVIEW project developed an integrated set of techniques and tools to address each of these challenges. The Army has long needed an assortment of modern tools to analyze military intelligence policy issues to complement and support the Cost and Operational Effectiveness Analysis (COEA) and master planning processes. Although these new tools are potentially valuable, to benefit from them, the Army needs to incorporate them into policy decisions. By employing them in actual studies, ways should be found to improve them and evolve still better methods.

RESEARCH OBJECTIVE AND APPROACH

The overall objective of the OPVIEW project was to develop and demonstrate a way to measure the operational value of intelligence, electronic warfare, and target acquisition (IEW/TA). More specifically, the project had four goals:

- Develop a way to quantify and measure IEW/TA contributions to combat and noncombat operations;[2]
- Test the methodology by applying the prototype models to support Army policy decisions;
- Develop analytic tools to support value assessments using the methodology; and
- Perform sensitivity analyses to assess IEW/TA's contributions across a wide spectrum of operations.

The research progressed through three phases: concept exploration, development of the methodology, and demonstration of the methodology. Each phase involved a large set of research tasks.

Concept Exploration

- Researched relevant publications;
- Interviewed key personnel in Army Operations and MI communities;
- Investigated and developed methodological approaches;
- Investigated alternative methodologies;
- Researched alternative models; and
- Selected methodology and model of choice.

[2]The desire to be able to assess low-intensity conflict and noncombat operations was discussed with James D. Davis but was not included in the project description. These capabilities were added as objectives during the last phase of the project when a way was developed to adjudicate noncombat operations. The method is described in Chapter Four and Appendix C.

Methodology Development Results

- Developed value-added scoring process;
- Employed subjective measurement approach;
- Developed supporting prototype models; and
- Developed a dynamic simulation value measurement process.

Methodology Demonstration

- Obtained databases from Army subject matter experts and other sources and entered data into the models;
- Applied and tested the methodology and models in trials; and
- Revised the methodology and models employing lessons learned from the trials.

Application

- Applied the methodology and models for special studies;
- Revised the methodology and models employing lessons learned from studies.

OVERVIEW OF RESEARCH RESULTS

This report documents the OPVIEW methodology and model development efforts. Included are several methods and processes that are designed to assist the Army in deciding which policies and research, development, and production programs to implement in military intelligence.

The study yielded four principal methodological products:

- An overarching analytic framework for measuring the operational value of intelligence;
- A methodology for measuring the value of intelligence on an aggregate level using a standard scale for all collection types (the "INTs");
- A static (time-independent) model for applying this measurement methodology across many conflict regions and conflict states; and
- A dynamic (time-dependent) simulation model for applying the measurement methodology to examine intelligence measures in a specific region and conflict state over time.

The analytic framework is presented below; the three methodologies are described in succeeding chapters of this report.

We believe the methods and processes developed in this study may be adaptable to other areas, e.g., space, command and control and communications. They are intended as tools to help analysts decide such issues and which policies to promulgate, which applied research programs to approve, which technologies to promote, and

which changes to make to Joint and Army doctrine, system employment strategies, and training programs. All of these aspects can contribute to improved policy analysis and decisions.

There are many possible future uses of the methodology and models. We also believe there is a need for a *Joint Information Effectiveness Manual (JIEM)* similar to the *Joint Munitions Effectiveness Manual (JMEM)* that would provide credible results to the analytic community and other users. Intelligence and conflict-related results would be derived for both the collection and production means and be evaluated under a variety of combat and noncombat situations and other environmental conditions. We recommend that the need for such a manual be analyzed.

THE OPVIEW ANALYTIC FRAMEWORK

Figure 1.2 provides an overview of the analytic framework. The framework

- Employs a top-down perspective and highly aggregated data;
- Begins with a mission statement and ends with assessment of mission accomplishment; and
- Represents results of various intelligence processes (e.g., collection planning, collection management), but does not explicitly model the processes themselves.

Use of the OPVIEW analytic framework is outlined in procedural steps below.

- Select regions and scenarios to be studied;
- Identify regional and campaign objectives;
- Specify campaign and engagement strategies;

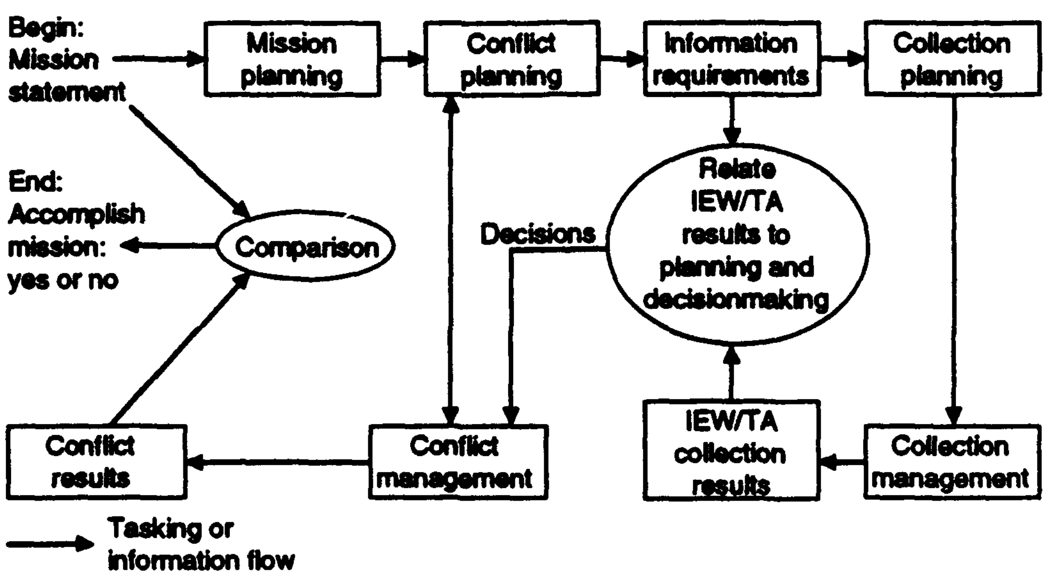

Figure 1.2—Overview of the Methodological Framework

- Specify missions and their operational phases;
- Develop campaign plan to execute missions;
- List information and intelligence requirements;
- Evaluate IEW/TA mixes, employing the OPVIEW static or dynamic simulation models (plus other tools as appropriate) to match IEW/TA capabilities for each region, mission, and phase of operations;
- Examine results for dominance of IEW/TA system types, or lack thereof;
- Perform additional analysis where the OPVIEW and other models and simulations do not sufficiently discriminate between IEW/TA inputs and operational outcomes;
- Recommend dominant and tailored force mixes (retain, acquire, or develop); and
- Perform value-scoring for input to PPBES or other program reviews listing added value of IEW/TA systems, system packages, and their force structure.

This procedure is a framework for analysis that can help the analyst develop insights by asking "what if" questions and narrowing the search for the preferred mix of IEW/TA assets and characteristics.

To be applicable to a wide variety of scenarios, the methodology was designed around a top-down approach. In this approach, intelligence asset capabilities are measured with respect to their purpose, i.e., their ability to support the commander's plan. (By contrast, a bottom-up approach would focus on collection-system characteristics and attempt to fuse this information into a coherent picture.) Because of this top-down approach, the OPVIEW methodology and models do not explicitly represent system-level activities such as the characteristics of signals or the number of threat emissions over time. Only the effects of activities by intelligence assets to provide the required information are presented.

In the OPVIEW approach, the plan is defined to accomplish the mission, the information requirements are defined to support the plan, and the intelligence assets are measured with respect to their ability to provide this information in a timely manner. In addition, the intelligence assets are measured with respect to their contribution to provide this information as part of an intelligence package, rather than as individual collection assets.

The primary measure is called the collection probability factor, or CPF. The CPF is the best a system can do to provide the required information, not accounting for degradations caused by conditions such as system failure (e.g., because of equipment, crew, direct support) or by terrain, weather, or enemy active or passive countermeasures. CPFs are defined to be between 0 and 1 where 1 represents perfect capability to provide the required information. The conditional collection probability factor, or CCPF, accounts for the effects of these capability modifiers and is also defined to be between 0 and 1.

Once CPF and CCPFs are established for each intelligence asset, one can measure the capability of a package (i.e., a mix of specific types and quantities) of assets to provide the required information under different degradations caused by environmental effects and enemy activity.

Since the OPVIEW models accept as inputs data that represent subjective expert judgments, we devised a disciplined, systematic, and rigorous approach to define and manage subjectivity. The intent was to limit and expose uncertainty as much as possible and to distinguish between those areas where general agreement exists, based on proof, and where consensus might be problematic.

We distinguish two levels of subjectivity in system performance measures. CPFs, the less-subjective measure, represent expert judgments of a system's performance under ideal circumstances given its design characteristics and physical laws. CCPFs, the more subjective measure, represent complex expert judgments that are based not only on the data that constitute CPFs, but also on data regarding expected environmental and operational conditions and the system's expected (usually degraded) performance under those conditions.

Since judgment has been used extensively to create both the CPFs and the degradation factors necessary to obtain the CCPFs, we needed a way to assure that these judgments were reasonable (and to test that reasonableness). The project investigated the subjective transfer function (STF) approach as a way to do so, although actually applying the methodology in this way would require a significant new effort—i.e., this project described an approach to verification and validation (V and V) but did not try to implement it.

Obviously, if the same scale and standard units are used each time the results would be the same, and all subsequent model runs using the OPVIEW methodology would be repeatable. Credibility depends on the extent that users agree with the values contained in the common scale of standard units they use for their analysis. Consensus is essential for credibility. Therefore, the analytic community that uses the OPVIEW methodology would be expected to use a series of tables prepared beforehand that contain the standard units and values and maintain them so that they are both as accurate as possible and agreed to by the community.

In our experience, military operations and intelligence experts are able to reach consensus readily in their judgments of system performance at both levels when given sufficient credible information. Moreover, when it is not available, they are better able to request the information they require to make their judgments. The quality (validity and reliability) of these expert judgments can and should be tested to improve the data.

Features of the Subjective Transfer Function Approach

The STF is an approach to estimating the effects of complex system factors on system outcomes using human judgments. Factors defining a system are selected by system experts and are hierarchically structured to represent the system under investigation. The approach incorporates the testability features of "algebraic modeling," developed in psychology. Factors are manipulated in experimental designs that allow tests among judgment theories (in the form of algebraic models) to explain experts' judgments. Typically, different groups of experts know about different aspects of a system. The theory that passes its explanatory tests for a particular expert group is the STF or underlying judgment theory for that group. The STF for each expert group estimates the effects of system capabilities on judged outcomes. The set of STFs across expert groups functionally interlink to produce an overall system effectiveness measure. The interlinking function feature eliminates some of the problems of using

assumed but untested rules for aggregating across hierarchical tiers found with other approaches. The resulting estimates may or may not be correct in predicting real-world outcomes, but they are "serious" estimates, systematically developed from aggregated expert judgments.

How the Methodology Works

The contribution of intelligence to operations always depends upon the operational situation. Since each situation is different, to determine how well or how poorly each system contributes, under varying conditions, it is necessary to perform analysis across many different kinds of relevant situations and summarize them. For this the OPVIEW methodology employs a standard measurement method, a value-added scoring process, and a dynamic simulation process. One key feature of the methodology is the ability to relate commanders' information needs, plus the time when the information is required to make a decision, with the capabilities of the various collection systems, and the times their results are made available to a decisionmaker, when the collection systems are employed in various desired ways in an operational setting.

Exploratory Modeling

The use of computer models for policy analysis has a fundamentally different character from what is classically considered modeling in engineering and the "hard" sciences. Models for the physical sciences are often used to make detailed predictions, and since part of policymaking will always be making predictions about uncertain events, "exploratory modeling" provides a way computer models can fruitfully be employed to support policy studies (Bankes, 1992).

The profound uncertainties inherent in warfare imply a need for aggressive sensitivity analysis for any conflict simulation model. Small changes in IEW/TA can provide large uncertainties in outcome, therefore, sensitivity analysis of a large number of different cases is especially important. Unfortunately, an exhaustive sensitivity analysis of all possible cases is not computationally feasible. For this reason, we employ an exploratory strategy of searching for key cases, relying upon the analyst's judgment to prioritize the scope of different uncertainties. Exploratory modeling allows for the flexible and economically practical allocation of human as well as computational resources to those aspects of the problem that are judged to be most important to examine at a given time.

The Variable Resolution Approach

Most models currently being used to investigate military issues are classified as being either high or low resolution.[3] An example of high-resolution modeling for SIGINT would be to examine each of the thousands of emissions in the radio and radar frequency bands by all of the enemy's command and control, fire support, and air defense systems, or for IMINT to examine each moving vehicle track detected by an MTI system. The aggregated, or variable resolution approach, which is employed by

[3]The Army FAM postprocessing model is considered to be mid to high resolution.

OPVIEW, begins at a much lower and more highly aggregated level and increases the resolution only when necessary. For the two examples just given, the model would start with inputs known to be attributable to a sensor system's capability to detect a type or class of a threat entity based upon the number of specified emitted signals, or MTI tracks, that are characteristic of the threat entity depending upon its activity state, e.g., advancing, attacking, retreating, hiding.

For analyzing some issues, either extreme is unnecessarily restrictive. If all of a model's operations are performed at high resolution, the amount of data generated and the time required to analyze results can be extensive. Moreover, contrary to the general view, capturing a great amount of detail does not necessarily contribute to the analytic process or make the results more credible. In fact, if all the details cannot be specifically accounted for, they can be very misleading and frustrating to the analyst. This is especially true for intelligence.

Imagine for a moment that every collection means and weapon and force interaction could be recorded and accounted for in a given conflict simulation. Efforts to measure the contributions of say, JSTARS, would not benefit by this unless a way was found to subtract the contributions of the other systems that may have played a part in providing or confirming the same intelligence obtained from JSTARS. We see this as an inordinately complex task that does not provide useful insight into the decisionmaking process. Moreover, although advances in computer science technology continue to be made that would enable the tracking and recording of a myriad of events on the battlefield, having such detailed information could be extremely difficult for the analyst to follow or interpret. Therefore, he would have to depend more and more on his ability to trust computer software, which does not provide most analysts with greater confidence because they are unable to track and comprehend the relevant events.

What is much more tractable is to be able to focus on the contributions of particular systems, first separately, then in combination with others. This requires a variable resolution approach that begins with the highest level of aggregation (low resolution) and is expanded, only when necessary, to the highest level of resolution required to provide answers.

In contrast, the opposite extreme is also unsatisfactory, for if the aggregation level is set too high, many important events will be summarized without enabling the analyst to examine them and gain important insights. The OPVIEW approach accommodates this by enabling the analyst to adjust the level of resolution to suit his needs. This is accomplished by placing in the model's database beforehand a series of tables with various levels of detail that pertain to both the collection systems and the threat entities to be analyzed. Then, with the aid of exploratory modeling, he can investigate those avenues he thinks are likely to reveal the answers he is seeking.

ORGANIZATION OF THIS REPORT

Chapter Two describes the OPVIEW methodology for the aggregate-level variable resolution measurement of intelligence collection and production capabilities. This methodology measures the potential and actual capability of intelligence assets to perform eight intelligence functions using a standard scale. The development of a standard scale permits the analysis of the value of alternative systems and system packages.

Chapter Three describes a static model for applying the measurement methodology to analyze the added value of intelligence assets. Sample graphic displays of the outputs are presented.

Chapter Four describes a dynamic model for applying the measurement methodology; the dynamic model is an operations simulation tool that permits the analyst to determine the operational value of intelligence over time in a specific (combat or noncombat operations) scenario consisting of any number of intelligence-collection arrangements and corresponding operations plan changes. As in Chapter Three, sample graphic displays of the model outputs are also presented.

Chapter Five presents conclusions regarding the achievement of the OPVIEW project in advancing the state of the art in military intelligence policy analysis and identifies needed future developments in the analytic tools and techniques. It also recommends a process for transferring the technology to the Army and suggests near-term applications of the OPVIEW methodology in Army decisionmaking to military intelligence policy.

Appendix A defines the terms used, and Appendixes B, C, and D supplement Chapter Four by providing detailed descriptions of the dynamic operations simulation model. Appendix B describes the decision submodel; Appendix C describes the intelligence submodel; and Appendix D describes the operations adjudication submodel.

Appendix E addresses data requirements for the two analytic models as well as the current and desired data sources.

Appendix F explains the STF approach for assessing the validity of judgments, a methodology that is useful for obtaining data inputs to the OPVIEW models with known validity.

Appendix G addresses some of the issues surrounding V and V of the OPVIEW models, which are complicated because the Army's current V and V policies and techniques do not fully address models of this nature (i.e., those that represent behavioral in conjunction with physical phenomenology).

METHODOLOGY FOR INTELLIGENCE MEASUREMENT

DESCRIPTION OF THE METHODOLOGY

The value of military intelligence is always a function of the operational situation. Therefore, there is no single *a priori* value that can be ascribed to a given type of sensor or other intelligence asset unless one first examines the performance of the asset in a wide range of situations.

The process for examining an asset's performance is described in this chapter. Briefly, it consists of deriving tables of standard values for each asset under a variety of operational settings and a wide range of situations. These values are to be validated by panels of experts, under the management system described in Appendix F, who rule on all objective and subjective data. The resultant standards should be changed whenever the experts determine they need to be and revalidated by experimentation when necessary.

By examining a wide range of situations, the values can be further validated. Initially, the analyst may try a single a priori value (a CCPF, which is described later in this section) provided in the tables. Subsequently, for each given situation the analyst studies, the a priori values would be revised and refined, then the new tentative values would be reviewed by the panel of experts who validate the standard units and changed if appropriate.

The methodology for aggregate-level variable resolution intelligence measurement has three purposes:

- Provide a common value-measuring system first, for each system, then across all collection means for various missions and their operational phases;
- Relate intelligence-collection capabilities to a commander's information and intelligence requirements; and
- Develop and compare alternative collection packages across various regions, conflict states, missions, and operational phases.

To arrive at a common scoring method, we analyzed over 300 prioritized intelligence requirements (PIRs) and information requirements (IRs) for both combat and non-combat operations. We determined that all information needs (or some combination of them) can be decomposed according to a standard classification scale of factors related to information about threat entities.

STANDARD CLASSIFICATION SCALE

This is the standard classification scale of factors. The listed categories are scaled according to their increasing requirement for resolution and location precision.

- Detect;
- Locate generally;
- Locate precisely;
- Classify;
- Identify;
- Track;
- Acquire as a target; and
- Assess operational status, including postattack residual capabilities and battle damage assessment (BDA).

COLLECTION PROBABILITY FACTORS

In the OPVIEW methodology, we assign each intelligence system a score indicating its potential capability, operational and environmental constraints aside, to perform each of the eight intelligence functions outlined above. We call this score the collection probability factor, or CPF. CPFs represent the full technical potential capability of a system to perform a specific intelligence function. They are ideal scores that must be discounted in specific scenarios to reflect the way the operational and environmental factors can be expected to degrade the performance of the system.

A CPF is expressed as a numerical function between 0 and 1, where 0 indicates no possibility of performing the specified function and 1 indicates a certainty to perform the function. The CPFs for collection systems were based, in part, on data provided to RAND by the U.S. Army Materiel Systems Analysis Activity (AMSAA) at Aberdeen, MD. AMSAA is responsible for obtaining these data from a variety of sources, including contractor reports, results of tests and experimentation, operational employment results, and technical intelligence reports (on non-U.S. systems).

CONDITIONAL COLLECTION PROBABILITY FACTORS

Because systems do not always perform ideally in operational settings, we developed an adjusted score called the conditional collection probability factor (CCPF). CCPFs are defined as CPFs modified to reflect the environmental and operational conditions affecting the performance of a collection system in a given region or theater. The environmental and operational factors considered in developing the CCPFs include system availability, and survivability, topography, weather, and passive and active countermeasures. Other factors may be added by including more tables and their data. Initially, CCPFs are derived from a wide range of scenarios and situations and are recorded in tables that are to be used for analysis in studies. The CCPFs that were thus derived for this study were obtained from AMSAA and other military experts and later resubmitted to AMSAA for validation.

The use of the methodology presupposes that analysts will have available previously prepared tables containing validated CCPFs. When performing analysis for studies, analysts would select the tables that are most suited to the scenarios and situations they wish to analyze.

Only when one or more of the existing CCPFs in the available tables do not meet their requirements at the time analysis is being performed would an analyst be expected to use judgment to arrive at a tentative CCPF value to continue the analysis. For example, if the table of CCPFs for a particular IR sensor operating in a jungle environment did not include the modified value for area coverage during light rain, but did contain values for no rain and for hard rain, the analyst might wish to extrapolate between the two extremes and temporarily use an intermediate value which, although subjective, would fall within a reasonably bounded range. However, for all studies, the intent is to use only CCPFs that have been validated.

This process of moving from CPFs to CCPFs transforms an IEW/TA system's measure of performance (MOP) to a measure of effectiveness (MOE). (See Appendix A for a discussion of different types of measures relevant to intelligence.) CCPFs are the assessed performance capability for each type system and mix (plus their reporting time) under specified environmental and operational conditions. A CCPF is an answer to the question, "Given that a threat entity exists (from ground truth) at a certain location and time, when operated in stated environmental and operational conditions, what is the probability that a particular system, or mix of systems, will detect, recognize, or classify, etc., the specified target?" Like the CPF, the CCPF is expressed as a probability value ranging from 0 to 1. AMSAA information provided to Army users of simulations generally takes the form of probability of detection or identification versus range. However, such information is derived from AMSAA's own simulations and models, many of which use a specific scenario to arrive at an estimate. Therefore, such information is already weighted for a given set of parameters in a specific scenario. The OPVIEW methodology is oriented on using information about the collection system (platform and sensor), and then determining how that system is affected by variables in different scenarios and environments. Therefore, we provided AMSAA analysts with the format and type of information that we desired. After discussions with AMSAA analysts concerning this information, we collaboratively arrived at the values between 0 and 1; final data for the prototype OPVIEW model were selected using best estimates by RAND scientists familiar with the laws of physics and the physical characteristics of intelligence systems as published in Army and Defense Intelligence Agency documents. Readers should be cautioned that this is a set of developmental data to illustrate the prototype methodology and not final data to be used in actual studies for the Army.

CCPFs are unitless because they are surrogates for probabilities. As probabilities, a specified event occurs, on average, for a fraction of time. The event must be carefully defined. The degree of coverage threshold is assumed to remain constant. In each case there is a specific coverage for a specified category (detect, locate, etc.) according to some threshold across the entire area of interest for a 24-hour period. As a result, there is a relatively linear measure as a fraction of 24 hours, or a fraction of coverage of the area of interest. One-third of the coverage can represent 8 hours of coverage over the entire area, or 24 hours of coverage over one-third of the area, or any combination thereof.

CCPFs can be used to define collection-system coverage results and information timeliness for a single IEW/TA system or a mix of collection capabilities. CCPFs are used to quantify system effectiveness over time.

For reasons of accuracy and credibility, RAND asked AMSAA to provide CPF and CCPF data for use by the OPVIEW project. AMSAA was able to provide information on which to base these values for some, but not all, of the intelligence systems. Consequently, RAND developed these values for the Army's pacing systems (the Army's IEW/TA systems currently in development) and submitted them to AMSAA for verification and comment.

The methodology was designed to reflect the ability of a given type of collection capability to support the commander's information needs in a given situation. Each sensor will contribute more or less to each of these tasks, and in a different manner that will vary depending on the situation. The commander will use his sensors to accomplish these tasks with respect to specific operational situations. For example, if he needs to know whether or not enemy forces are present along a given avenue of approach, he may want only to *detect* and *generally locate* the enemy forces. If, instead, he wants to know if enemy forces have reached a specific bridge, he may need to precisely locate one or more threat entities. Alternatively, if he needs to know the location of the enemy's armored units, he may want to *classify* the units. If the commander needs to know if the enemy has already committed his reserves, he may want to *identify* the units. If he wishes to target and attack specific units, he will need to *track* and *acquire* the targets. And if he needs to know whether or not a given unit is operationally effective, he will want to *assess the operational status* of the enemy unit.

Note that the commander does not need to know every bit of information about every enemy unit all the time. The situation he faces will determine what specific information he needs when, where, and to what degree of accuracy.

MEASUREMENTS WITH THE METHODOLOGY

Measuring Synergism Among Collection Systems

One use of CCPFs is for scoring synergism when two or more IEW/TA systems are operated together (as cuers, warners, or information augmenters in the same operational setting). First, the CCPFs are developed for each system when operated independently of the other systems in a package. Second, a CCPF measure is calculated for the mix of systems in a package. The values may be derived by judgment, or experimentally through field tests, or from operational data.

Figure 2.1 presents these functions in a display that is intended to suggest that, taken in the order from left to right shown on the slanted line in the figure, they represent generally increasingly demanding collection requirements in terms of two values, i.e., *resolution* and the probability of performing the function (detecting, locating, etc.) and the *timeliness* requirement for reporting.

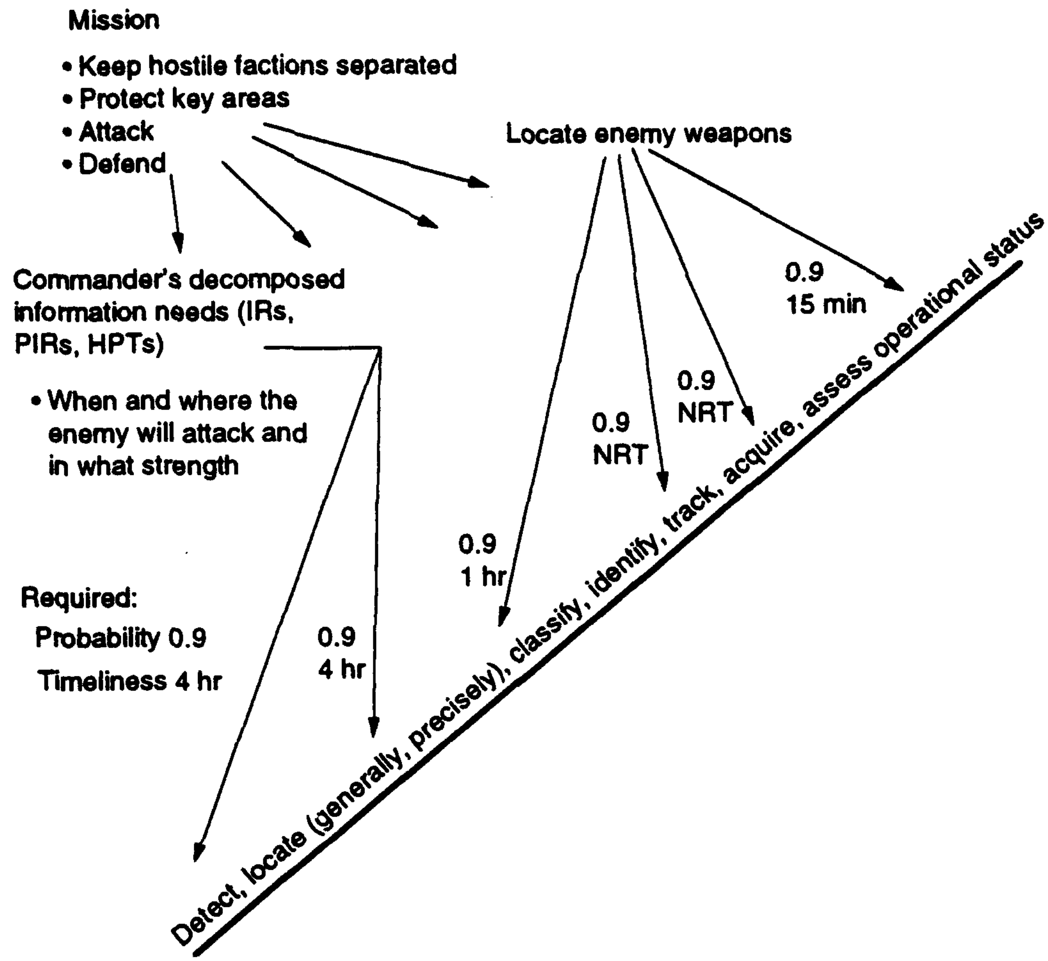

Figure 2.1—Probability and Timeliness Requirements for Commander's Information Needs According to the Standard Classification Scale

Integration of Collection Results

The use of this scale makes possible the otherwise intractable task of trying to integrate a variety of technical information reports, derived from dissimilar collection categories, i.e., IMINT, SIGINT, MASINT, HUMINT, into a standard scheme that applies to all the means of collection. In the field, part of the analyst's production task is to integrate the results of tactical intelligence reports (TACREPs) received from all the "INTs," e.g., IMINT, SIGINT, MASINT, HUMINT, and then relate the collated information to form a composite image of the conflict area. *However, TACREPs of* collection results are dissimilar across all the "INTs."

For example, most SIGINT TACREPs consist of technical reports about electronic emissions from threat entities according to their operating system types, e.g., radios, radars, or control data links, and are related to the frequency bands, number, loca-

tion, and time of COMINT or ELINT intercepts.[1] IMINT TACREPs consist of reports of photographic imagery interpretations about the shape, dimensions, quantities, etc., of man-made objects and their surroundings. The scale above permits the analyst to integrate the results of various IEW/TA collection efforts at a level that is common to all, rather than to attempt to integrate them at the dissimilar TACREP level.

In the OPVIEW methodology, each "INT" product is expressed as a measured assessment of the collection process' capability to perform one or more of the scored tasks pertaining to one or more categories of threat entities. The results from any of the other "INTs" that are employed may also add confirmation, if they are capable of doing so (both in terms of their technical/physical ability and the operational employment opportunity) to add to the assessment. If they cannot contribute, or if their measures are of a lower value or less timely, their results are not considered in either the value-added scoring process or the dynamic simulation process. Only the results from the most capable, best positioned, and least obstructed IEW/TA systems are used so that less well-informed collectors, or those that produce less timely results, do not contribute competing results.

Figure 2.2 illustrates the way integrated collection system results are matched to commanders' information needs across the spectrum of requirements for a region and for each mission. The analyst can design alternative IEW/TA collection, production, and information-dissemination packages by varying system and mix types and quantities to suit the mission requirements for each scenario to encompass all those needs.

Total Time for Collection, Production, and Dissemination of Intelligence

Total time is the measure we use to account for the elapsed time for intelligence collection and production operations to take place and for the dissemination of collected results to operational planners and unit commanders. Included in total time is the typical time—derived from experience and depending upon the command level and the connectivity architecture for the systems employed—that would actually be taken to complete the essential operations of collection, production, and dissemination in a given region or theater. Put another way, total time is the combined time required to pass data or information through a network of paths and nodes in a specified system's connectivity architecture for those operations to occur.[2]

The total time for a single network design—consisting of a single uninterrupted (nondelayed) path between a collector and a user—is measured as 1.0. Other more complex network designs that take longer to pass information along are compared to this standard and measure between 0 and 1.0. Examples of current and conceptual system connectivity architectures are illustrated in Figures 2.3 and 2.4.

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[1]Another category of SIGINT TACREPs pertains to the internal contents of intercepted messages (provided they can be understood). Since the actual value to a decisionmaker in a given operational situation would be extremely difficult, if not impossible, to measure, the ability of comparable collection systems is analyzed instead, based upon the quantity and timeliness of messages that can be intercepted over time.

[2]For example, when comparing the processing time for two similar collection systems, e.g., photo imagery or MTI, the times required to interpret the results are compared for like systems.

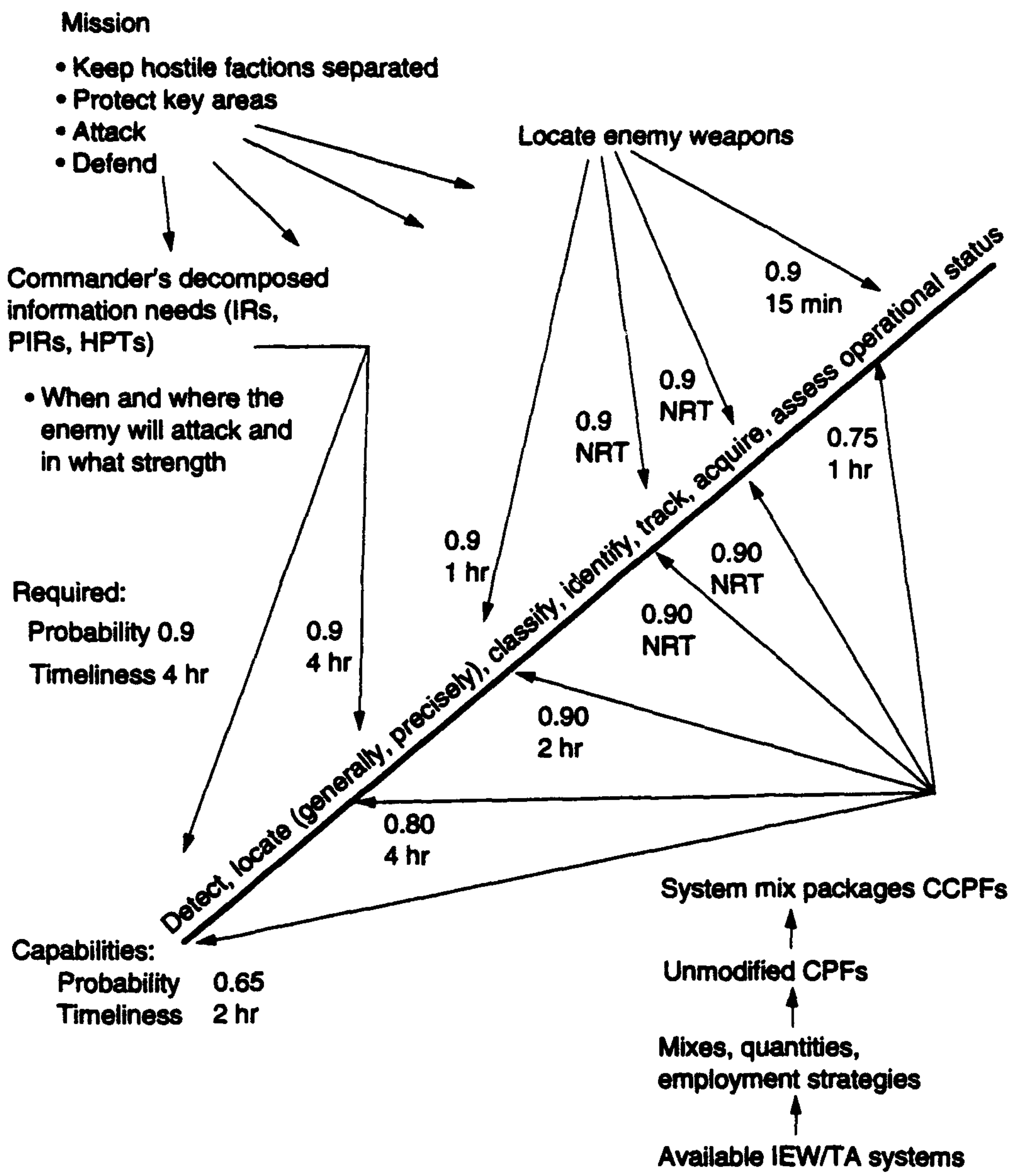

Figure 2.2—Commander's Information Needs Matched to System CCPF and Information Timelines Capabilities According to the Standard Classification Scale

The architecture in Figure 2.3 represents the current serial data flow method, whereas that in Figure 2.4 represents a more parallel and, therefore, timely architecture employing simultaneous broadcasts to the major components and users in a network of systems, nodes, and links.

APPLYING THE AGGREGATE-LEVEL MEASUREMENT METHODOLOGY

As will be demonstrated in the following chapters, the methodology for aggregate-level intelligence measurement can be applied to assess and analyze the contribu-

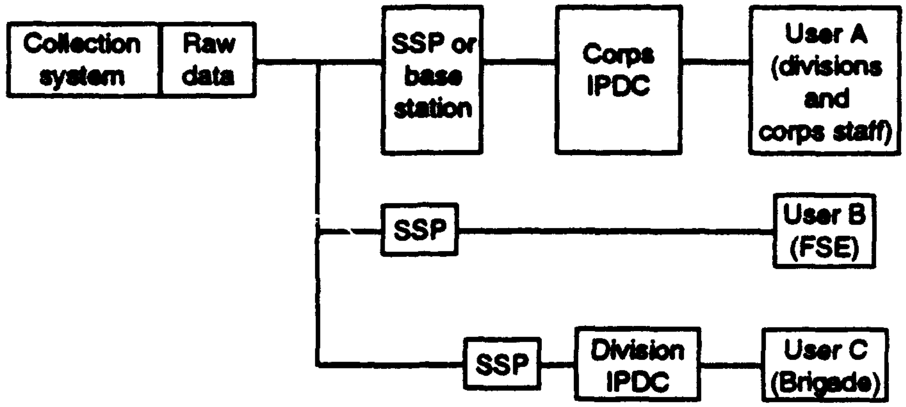

Figure 2.3—System Connectivity Architectures for GRCS, UAV, AQF, ASARS

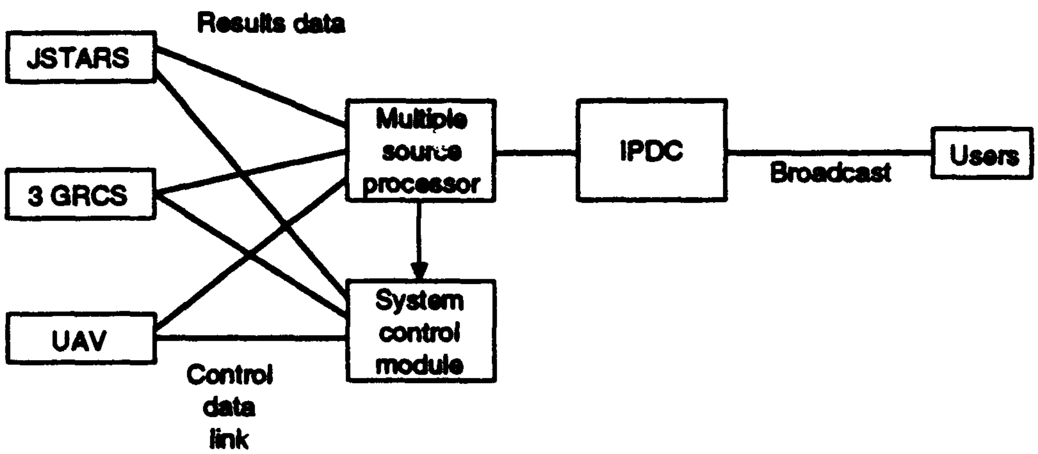

Figure 2.4—Recommended Future Conceptual System Connectivity Architecture

tions of individual systems and system packages across a variety of scenarios, using the standard method described.

The methodology, which we envision being used by both the Army Staff and the U.S. Army Intelligence Center, should prove useful to other government intelligence agencies. It provides a disciplined approach to making the necessary resource allocation decisions. When combined with analysis of economic production, manpower programs, and the total military force to be supported, the methodology could provide acquisition managers and decisionmakers with a clearer and more substantial basis for structuring and enunciating the benefits of their programs for the DoD Program Objectives Memorandum and for the Presidential Budget submission to Congress. A brief description of the static model is provided in this chapter; a fuller account is contained in Bondanella et al. (1993), Appendix B.

Chapter Three

APPLYING THE METHODOLOGY USING THE STATIC MODEL

The static (or time-independent) analysis model is designed to be broad in scope but with limited detail. The model is designed to assess the ability of individual intelligence systems and system packages to contribute toward meeting a commander's intelligence requirements in specified scenarios. The model is called static because capability is assessed over the course of the scenario as a whole, not through time as the scenario develops. (The next chapter describes a more detailed model that can be used to make such dynamic assessments.) The model can be used analytically to determine the marginal contribution of new or alternative systems or to design system packages of varying capability. The current version of the static model employs a Microsoft Excel spreadsheet program run on a Macintosh computer. A brief description of the static model is provided in this chapter; a fuller account is contained in Bondanella et al. (1993), Appendix B.

The end result is an estimate of the added value by each type of sensor to perform a specific task that reflects the general (static) situation in a given region of operations.

MAJOR STEPS IN APPLYING THE STATIC MODEL

The static model provides a structure for analysis, but many of the measures are made and tradeoffs are done using subjective judgments. The major steps involved in employing the static model for analysis are listed below.

Steps

- Select regions and scenarios to be studied;
- Identify regional and campaign objectives;
- Specify campaign and engagement strategies;
- Specify missions and their operational phases;
- Specify sensor area coverage and total time requirements to meet typical or desired operational needs;
- Define minimum essential and preferred intelligence asset packages to be analyzed;
- Specify expected coverage by both the minimum essential and preferred packages;

- Specify total times according to system connectivity architecture; and
- Specify responsiveness as a function of tasking (e.g., Air Force assets that are not allocated by Army commands and, therefore, may be less responsive to an Army commander's needs).

Application Procedure

The principal steps in the OPVIEW process employing the static model are outlined here. The first two steps depend upon CPFs and CCPFs either already available from AMSAA or from elsewhere in the military/analytic community and listed in tables ready for the analyst to use. The remaining five steps pertain to work by the analyst when applying the data to perform studies.

- Start with the basic CPFs for each type asset for each intelligence task (detection, locate generally, locate precisely, classify, identify, track, acquire, and assess residual operational capability).
- Modify these basic CPFs by applying multipliers to account for the effects of terrain (topography and vegetation), weather, and enemy countermeasures (active measures, including air defense artillery (ADA), jamming, smoke), and passive measures (including camouflage and controlling the sensor's or platform's electronic emissions), yielding CCPFs.
- Weight the importance of each intelligence task as a function of the mission being performed in each region and scenario (combat or noncombat).
- Specify a minimum and a preferred intelligence package to provide a base "score" for each type of asset for each region and combat state.[1]
- Modify the score of each type asset by a multiplier to reflect any lack of timeliness for time-sensitive missions, and a multiplier to reflect any lack of allocated support to operational missions (e.g., space assets that support numerous other users and, therefore, may affect timely support to each).
- Vary the composition of the preferred package individually for each type asset and record any change in the score. The change in score, based upon variations in the package, defines the added value for that type asset for that region, mission, operational phase, and conflict state.
- Determine the minimum required assets by summing the two highest minimum required numbers of assets across all missions.[2] (A maximum of two is based upon the assumption that the United States will not be simultaneously engaged in more than two contingencies.)

[1]The quantity and types of collection assets initially chosen for each package would depend partly on their area coverage capabilities (which can be graphically portrayed by the dynamic model), the number and types of systems available, and other factors that bound the conditions of each particular study.

[2]Note that if one drops below the assumed minimum essential package, the assumption of linearity in degradation no longer applies. As mentioned above, synergistic effects are assumed to be represented by the minimum essential package.

VALUE ADDED DEFINED

We defined the term "value added" as the potential contribution to military operations of a single system or group of systems to perform a given intelligence-collection or production function when compared with either additional units of the same system, or with a different type of system that can perform the same function. For example, an intelligence-collection system such as JSTARS can detect, locate generally or precisely, and track mobile threat entities. An example of value added here would be two JSTARS over one. In some cases there may be no difference or the additional system would serve only to back up the primary system. The value added by another kind of MTI system might be similarly measured, e.g., one installed on a UAV platform would have a much smaller field of view and, hence, would require more units to provide the same area coverage in the same period of time.

The value of "cross-INT" trades is arrived at by comparing results obtained from various combinations (type and quantity mixes) of different systems to do the same job. Obviously, other factors must also be examined and assessed. For example, even though it might be possible to detect, locate, etc., a desired number of threat entities in the same amount of time with two different packages, the force structure, system vulnerability, or operational limitations may favor one package over the other one. Both within-INT and cross-INT trades are measured as a function of specified minimum essential and preferred system packages.

Our analysis of minimum essential and preferred system packages was based on the following assumptions:

- The minimum essential packages are designed to account for any major synergistic effects between types of assets. For example, if JSTARS is being used to cue UAVs, then JSTARS should be in both the minimum essential and preferred packages. The interactions of possible synergistic effects are not explicitly represented in this methodology (only implicitly represented based upon this assumption).
- The preferred package is defined assuming coverage 24 hours a day (where appropriate), over all major areas of interest, at the desired level of accuracy.
- It is assumed that any reduction in the number of assets in the preferred down to the minimum essential package will result in a linearly scaled reduction in coverage. For example, if two assets provide coverage 24 hours a day, one asset will provide coverage 12 hours a day. Note that if one drops below the assumed minimum essential package, the assumption of linearity in degradation no longer applies. As mentioned above, synergistic effects are assumed to be represented by the minimum essential package.

ARCHITECTURE OF THE STATIC MODEL

The static model is arranged in the following manner on Microsoft Excel spreadsheets on a Macintosh computer. Starting at the upper left in Figure 3.1, the basic CPFs are stored for each collection asset under ideal conditions. There are 11 folders, one for each scenario, combining information on region and conflict state. Within each scenario folder are spreadsheets that contain the parameters and calculations

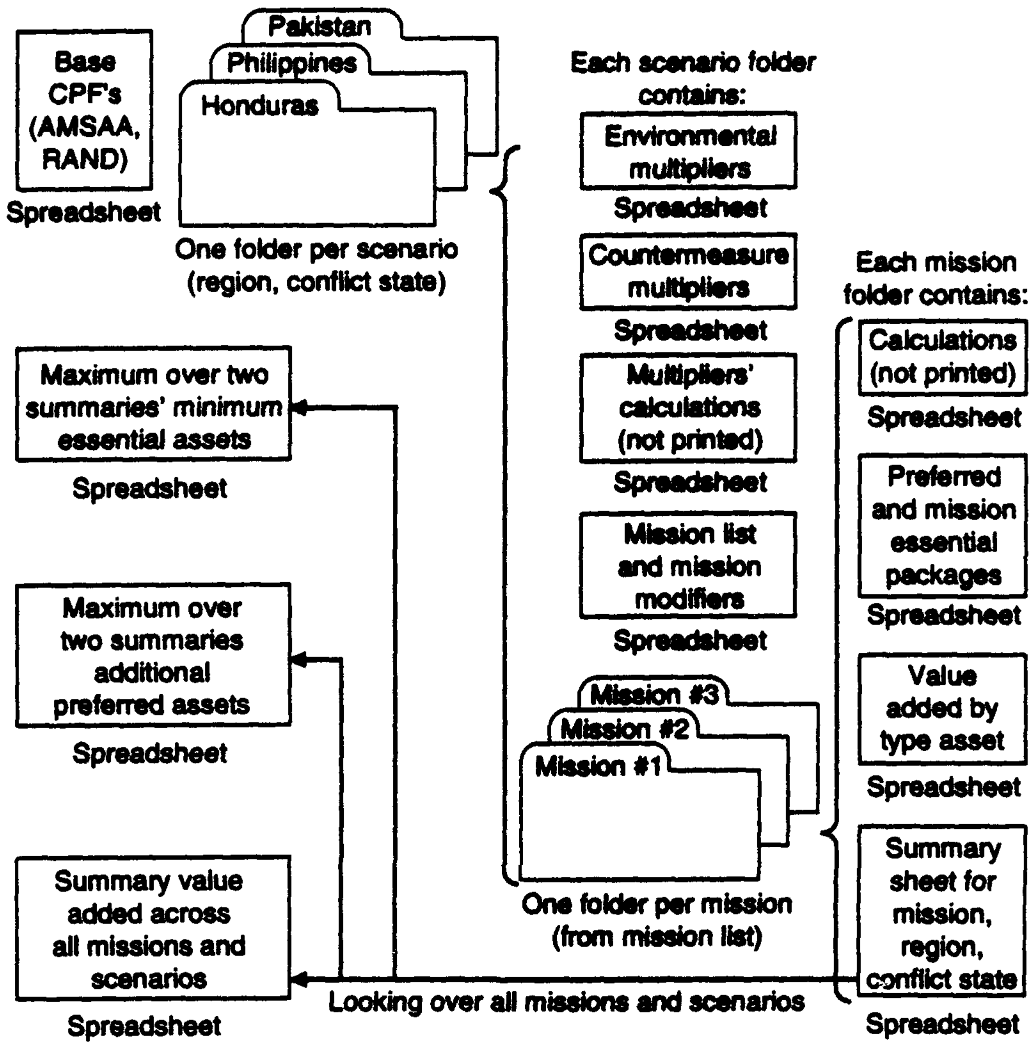

Figure 3.1—Value-Added Scoring Process for Determining Intelligence System Packages

for the environmental and countermeasures degradation effects. There are also discount factors for the eight intelligence tasks (detect, locate generally, etc.) as a function of the missions being performed in that scenario. Each scenario folder currently contains between one and four missions.

Each mission folder contains the definition of the minimum essential package to perform operations in this region and conflict state. The folder also contains the definition of the preferred package to better support operations in that scenario. If there are any synergistic considerations, such as JSTARS cueing UAVs for targeting purposes, these interactions must be accounted for in the definition of the minimum essential package. To retain its simplicity, the static tool is not designed to model such synergistic interactions explicitly. The mission folder also contains discount factors for timeliness (if slower assets are being used to fulfill real- or near-real-time requirements based on the timeliness criteria), and for availability (i.e., if not an Army system, it may not be sufficiently responsive when needed).

The results are aggregated and combined for each scenario, and the maximum requirements for each type asset over two scenarios are obtained.

ILLUSTRATION OF THE STATIC MODEL

The steps and tables listed below provide a narrative description of the computational steps contained in the software's application; however, the methodology itself is independent of any specific software application. For each step in the process, we will use a simplified numerical example to illustrate the calculations, consisting of only two types of intelligence assets (Type #1 and Type #2), and two categories of sample CPFs for intelligence functions (detection and acquisition).

Step 1: Begin with the base collection probability functions (CPFs) for each type of system. The initial CPF estimates were obtained from AMSAA; the final data for the prototype OPVIEW model were selected using best estimates by RAND scientists familiar with the laws of physics and the physical characteristics of intelligence systems as published in Army and Defense Intelligence Agency documents. Readers should be cautioned that this is a set of developmental data to illustrate the prototype methodology and not final data to be used in actual studies for the Army. These CPFs describe the probability of success for each of the following intelligence categories: detection, general location, precise location, classification, identification, acquisition, tracking, and poststrike residual operational capability assessment. See Table 3.1.

Table 3.1

Sample Raw CPFs

System Type	Intelligence Category	
	Detection	Acquisition
#1	0.8	0.6
#2	0.6	0.4

Step 2: Since the CPFs assume an ideal region with flat terrain, clear weather, and no threat, we need to modify these basic CPFs to better apply to a specific region and conflict situation. The following three multipliers will be defined for each CPF by system, intelligence category, region, and conflict state: terrain, weather, and enemy countermeasures. See Table 3.2.

Table 3.2

Sample CPF Modifiers

System Type	Factor	Intelligence Category	
		Detection	Acquisition
#1	Terrain	0.90	0.95
	Weather	0.90	0.90
	Countermeasures	0.95	0.95
#2	Terrain	0.98	0.99
	Weather	0.90	0.90
	Countermeasures	0.90	0.90

To obtain these multipliers, we estimated the portion of the terrain that had limited, open, and mixed line of sight. Mountainous, forested or jungle, and urban terrain were all considered to be closed, that is, to have a limited line of sight to a potential target. Flat terrain with sparse vegetation was considered to be open terrain, with good line of sight to a potential target. Combinations in between were considered to be mixed terrain (Huschke, 1990). We examined the types of terrain in the areas of interest and estimated the fraction in each of these three categories. These fractions were summed to the number one. For example, in the area of interest, the terrain may be 40 percent clear, 35 percent mixed, and 25 percent closed.

In addition to terrain, we estimated the weather that would occur in the region over the course of a year and divided the weather into three categories: clear, cloudy or rainy, and stormy. Using broad, annual estimates of rainfall and cloud cover in each region, we were able to estimate the fraction of time the weather fell into one of those categories. The weather fractions also summed to the number one. For example, the weather in the area and period of interest may be 50 percent clear, 30 percent cloudy, and 20 percent stormy.

The third component required is the effect that the terrain and weather had on the different types of platforms and sensors (Lund and Shanklin, 1972).[3] The effects are used as multipliers of the base CPFs. These values may be found in the "environmental multipliers" tables for each region in the spreadsheet. The agency responsible for maintaining the OPVIEW model should develop or acquire the data for tables for all the environmental multipliers for the scenarios and studies the Army is interested in conducting. The multipliers in the center of the table were considered constants over all regions, since each multiplier represented how much degradation to the CPF resulted from being in one type of terrain and weather condition. However, the fraction of time in closed, mixed, and open terrain varied from region to region, as did the fraction of time in each weather condition. The basic environmental multipliers were multiplied by the fraction of time in each type of terrain and the fraction of time in each type of weather. The result was an estimate of the degradation associated with each type platform and sensor caused by terrain and weather effects.

The countermeasure multiplier consisted of one multiplier for active countermeasures and three multipliers for passive countermeasures: smoke, camouflage, and emission control (the original values are based on various frequency bands in the electromagnetic spectrum, but the analyst should also consider effluents, physical shapes, etc.). Active countermeasures include attacks or threats of physical attack on platforms and sensors, and active jamming. We assumed that active threats were the smallest in peacekeeping operations, increasing in noncombat military operations, and highest during combat operations.

For passive countermeasures, we assumed that smoke would usually not be employed in peacekeeping and other noncombat operations but would be used primarily during combat operations, especially near the FLOT. The degradation of SIGINT

[3]More than three years of three-hour high-contrast whole-sky photographs, sky-cover observations, and cloud-type observations were used to develop two methods for estimating cloud-free line-of-sight probabilities through the entire atmosphere for any desired geographical location. One method requires a knowledge of the probability of each sky-cover category (tenths or eighths); the other method requires both sky-cover and cloud-type information.

assets because of enemy emission control was considered highest in static, non-combat situations, decreasing to less degradation in more fluid and combat-oriented situations.

The active and passive multipliers were all multiplied together into a composite for each category of asset. These multipliers appear in the "countermeasures multipliers" tables.

Step 3: Multiply the basic CPFs in step 1 by the multipliers in step 2 to obtain the modified CCPFs for each region and conflict state being examined. See Table 3.3.

Table 3.3

Sample Modified CCPFs

System Type	Intelligence Category	
	Detection	Acquisition
#1	0.62	0.49
#2	0.48	0.32

Step 4: Select one combination of region and conflict state and repeat steps 4 through the end for each region and conflict state. See Table 3.4. To facilitate this selection of the appropriate parameters for each region and conflict state, a separate folder was created for each scenario, as shown in Figure 3.1.

Table 3.4

One Modified CCPF Set

System Type	Intelligence Category	
	Detection	Acquisition
#1	0.62	0.49
#2	0.48	0.32

Step 5: Define a sequence of events in a specific region and conflict state. For example, in the Southwest Asia conventional combat scenario, there were three phases, comprising a total of four missions, as depicted in Table 3.5. Each phase and mission combination may define somewhat different intelligence requirements for a particular region and conflict state.

Table 3.5

Sample Sequence of Events

1. Preconflict phase
   - Mission 1: Indications and warning
   - Mission 2: Crisis management
2. Conflict phase
   - Mission 3a: Campaign planning
   - Mission 3b: Campaign execution
3. Postconflict phase
   - Mission 4: Reconstitution

Step 6: For a single mission in a specific conflict phase, region, and conflict state, provide ranked priorities for each intelligence category (categories are listed in Step 1). These priorities would depend upon the focus of the study. For example, during the indications and warning mission, certain intelligence assets would receive higher priority than others because of the kind of information they can provide and their importance to operations during that particular mission. Repeat steps 6 through the end for all missions and phases of conflict. To facilitate the selection of appropriate parameters for each mission, a separate folder was created for each mission, as illustrated in Figure 3.1. See Table 3.6.

Table 3.6

Sample Mission CCPF Modifiers

Mission	Intelligence Category	
Type	Detection	Acquisition
1.a.	8	4
(Normalized)	0.67	0.33

Step 7: Calculate the number of intelligence assets by type needed to ensure that the mission can be accomplished given the conflict region and conditions, required area coverage, number and types of threat entities, and expected losses to enemy attacks and expected crew and equipment losses. The quantitative assessments for each of these factors would be predetermined and validated by military experts for the analysis and listed in tables ready for analysts to use. This would be labeled the *preferred* group of intelligence assets to accomplish this mission given the conflict state and region. Since the CCPFs in steps 1 through 4 have been defined for a single group of assets, we need to determine the number of collection assets needed to provide a required level of accuracy continuously 24 hours a day and cover the whole area of interest. For example, if three intelligence assets are required to triangulate for purposes of target acquisition (standard practice), and six sets of these assets are required to provide coverage 24 hours a day, and three sets are required to cover the area of interest, then 36 assets of this type are required for the preferred intelligence package. See column one of Table 3.7.

Table 3.7

Sample Preferred and Minimum Essential Packages

System Type	Preferred Package	Minimum Package	Difference
#1	36	24	12
#2	20	14	6

Step 8: Calculate the number of intelligence assets by type needed to ensure that the mission can be accomplished, with an acceptable (stated) risk factor, given the conflict region and conditions, required area coverage, number and types of threat entities, and expected losses to enemy attacks and crew and equipment losses. All would be validated by subject matter experts and listed in tables ready for use by analysts. This would be labeled the *minimum essential* group of intelligence assets required to accomplish this mission with acceptable risk. As guidance, one may

accept reduced accuracy as defined by the CCPFs, or coverage less than 24 hours a day, or not covering the whole area of interest at the same time. To continue the above example, the requirements for precise location (which is needed for targeting) are less stringent than during the combat phase. As a result, we may require only two assets per group for accuracy that is less precise but still adequate for triangulation, and thereby require only 24 of these assets to accomplish the mission. See column two of Table 3.7.

Step 9: For every type asset where there are no assets in the preferred package as defined in step 7, set the CCPF rows in Table 3.8 to zero. This reflects that fact that only the intelligence assets present can contribute to the CCPF values in this mission. Since our preferred package example has assets of both types, Table 3.8 is the same as Table 3.4 in this case.

Table 3.8

Modified CCPF Set for a Preferred Package

System	Intelligence Category	
Type	Detection	Acquisition
#1	0.62	0.49
#2	0.48	0.32

In addition, not every asset is equally available to provide the required degree of accuracy for 24 hours a day over the whole area of interest. Therefore, we apply two additional multipliers to each type of asset. The first is an allocation factor that reflects the amount of time that type of asset is available to support the mission. For example, space assets may satisfy Army tasks only 10 percent of the time. Therefore, the allocation multiplier for space assets is set to 0.10.[4]

The second multiplier is a time discount factor that is applied only to missions that are time-sensitive. For example, campaign planning and execution have longer time requirements than attacking targets, and therefore the contribution of asset types with long response times is degraded. However, for missions without such restrictive time requirements, such as campaign planning and locating guerrilla base camps in a low-intensity conflict (LIC) scenario, no degradation factor is applied. Both of these multipliers may be varied by mission and scenario and are located in the spreadsheet designated "PrefMinPkg" (preferred and minimum essential packages). In our example, assume there are no additional degradations to asset types 1 and 2 owing to time and availability factors.

Step 10: Multiply all the elements in the columns of the preceding table by the intelligence mission category weights defined in step 6. To continue our example, the requirement to detect enemy assets during the indications and warning phase may be twice as high as the requirement to acquire targets. As a result, the normalized weight for the detection category will be twice as large as the normalized weight in the acquisition category. Therefore, the resulting CCPFs will reflect the different intelligence requirements by mission and phase of conflict. See Table 3.9.

[4]For purposes of analysis, one could compare the number of Army requests for space asset intelligence data during Desert Storm with the number of those requests that were satisfied.

Table 3.9

Modified CCPF Set After Mission Category Multipliers Have Been Applied

System Type	Intelligence Category	
	Detection	Acquisition
#1	0.42	0.16
#2	0.32	0.11

Step 11: Sum the columns of the preceding table. Verify that the column sums are nonzero for every nonzero normalized category weight defined in step 6. If not, go back and add appropriate assets to the preferred package to meet the mission requirements. See Table 3.10.

Table 3.10

Column Sums of Modified CCPFs for This Mission

System Type	Intelligence Category	
	Detection	Acquisition
#1	0.42	0.16
#2	0.32	0.11
	0.74	0.27

Step 12: Sum the rows of Table 3.10.[5] The row sums (in Table 3.11) represent the contribution of each system in the preferred package to the total ability of each package to meet the mission requirements.

Table 3.11

Row Sums of Modified CCPFs for This Mission

System Type	Intelligence Category		Row Sums
	Detection	Acquisition	
#1	0.42	0.16	0.58
#2	0.32	0.11	0.43
	0.74	0.27	

Step 13: Sum the row sums to determine the total mission "score" for this package. See Table 3.12. These scores represent the capability of each package to meet the intelligence mission requirements for this region, operational phase, and conflict state.

[5]Although we examined many different combinations of normalized and nonnormalized measures for the composite CCPFs, we concluded that a row sum would be an adequate measure for the MI 2000 Relook study. One may choose to normalize these values differently, depending on the needs of one's studies.

Table 3.12

Total Preferred Package Score of Modified CCPFs for This Mission

System Type	Intelligence Category		Row Sums
	Detection	Acquisition	
#1	0.42	0.16	0.58
#2	0.32	0.11	0.43
	0.74	0.27	1.01

Step 14: Normalize the row sums calculated in step 12 by the mission sum for this package. See Table 3.13. The row sums for each asset will all be less than one and sum to one. This step is necessary to ensure that assets are compared on an equal basis for all type missions. Without this step, packages with more types of assets would have a higher total mission score, and therefore a higher value added, which would bias the results. With this step, the fraction that each type asset contributes to the accomplishment of the mission is defined.

Table 3.13

Normalized Preferred Package Score of Modified CCPFs

System Type	Intelligence Category		Row Sums	Normalized Sums
	Detection	Acquisition		
#1	0.42	0.16	0.58	0.57
#2	0.32	0.11	0.43	0.43
	0.74	0.27	1.01	1.00

Step 15: Determine the value added for each intelligence asset in the preferred intelligence package for this mission. Although the process of combining CCPF scores to arrive at Value-Added results employs simple mathematics, the power of the methodology lies in quantifying the CPFs and CCPFs and their organization, and not in the process of multiplying, adding or subtracting their values. The following process is to be repeated for each type of asset in the preferred package for this mission.

a. For one type asset, find the difference between the quantity of this type asset in the *preferred* package and the quantity in the *minimum essential* package. This is the difference in the number of assets that will be used to determine the value added per asset. This difference was already calculated in Table 3.13.

b. Take the number of assets in the minimum essential package and divide it by the number of assets in the preferred package. In our example, 24 assets in the minimum essential package compared to over 36 assets in the preferred package gives a 2/3 (or .67) ratio for type #1. See Table 3.14.

c. Multiply the normalized row sum for this asset as defined in step 14 by the ratio defined in substep b above. This determines the reduction in the row sum of this asset's contribution to the total score for the package.

Table 3.14

Calculating the Value Added for One Type Asset for One Mission, Region, Conflict State

System Type	Row Sums	Normalized Sums	System Multiplier	Reduced Row Sum
#1	0.58	0.57	0.67	0.38
#2	0.43	0.43		0.43
	1.01	1.00		0.81

d. Find the difference between the new package score defined in substep c and the preferred package score as defined in step 13. In this case, the new package score is 0.81, which is 0.19 less than the preferred package score. This means that the 12 systems of type #1 contribute 19 percent of the achievement of the intelligence mission with respect to the preferred package for that mission in this region and conflict state. The average value-added score of one asset of type #1 to the preferred package for this mission in this region and conflict state is 0.016 points. We will use the value added by each system in our comparisons below. This estimate of value added is valid only when applied to the preferred package for this mission, region, and conflict state. See Table 3.15.

Table 3.15

Sample Value Added for Both Systems in the Preferred Package for Mission 1A

System Type	Preferred Package	Minimum Essential Package	Difference	Value Added by Each	Total Value Added
#1	36	24	12	0.016	0.19
#2	20	14	6	0.022	0.13

NOTE: The use of three significant digits does not imply a high degree of computational accuracy. Those numbers are derived by dividing the Total Value Added by number of assets. The final result should be interpreted as the average value added per asset, which usually is a smaller number than the two-decimal-place Total Value Added. The only reason Total Value Added is two decimal places is that it represents a probability of an event occurring, and probabilities are usually represented to two decimal places (e.g., 0.45 is 45 percent).

Step 16: Determine the minimum number of assets of each type required over all regions and conflict states. First, find the maximum number of assets of each type required in the minimum essential package across all mission types within a region and conflict state. Second, find the sum of the two largest minimum numbers of assets across all regions and conflict states. Since we are planning for at most two major contingencies at a given time, the two largest requirements for each type asset across all regions and conflict states will satisfy this two-contingency requirement. We define this list of assets and their quantities as the "class A" assets, which are listed above the line and will not be cut.

For our example, let us assume that we have repeated the above steps for another mission, preferred package, region, and conflict state. Our sample values for the second example are given in Table 3.16.

Table 3.16

Sample Value Added for Three Systems in the Preferred Package for Mission 2

System Type	Preferred Package	Minimum Essential Package	Difference	Value Added by Each	Total Value Added
#1	48	39	9	0.010	0.09
#2	41	25	16	0.007	0.11
#3	12	8	4	0.010	0.04

NOTE: See note on Table 3.15.

Step 17: Determine the number of "class B" assets that will be included below the line and may be cut because of funding shortages. Use the same procedure as described in step 15. First, find the maximum number of assets of each type required in the preferred package across all mission types within a region and conflict state. Second, find the sum of the two largest preferred assets across all regions and conflict states. Since we are planning for, at most, two major contingencies at a given time, the two largest requirements for each type asset across all regions and conflict states will satisfy this two-contingency requirement. The difference between the preferred quantity of assets and the minimum essential quantity of assets is the number of these assets considered below the line, which may be cut if funding shortages require. See Table 3.17.

Table 3.17

Number of Systems in Classes A and B

Class of System	System Type	Quantity
A	#1	62
	#2	39
	#3	8
B	#1	22
	#2	22
	#3	4

Step 18: Compare the value-added scores for each type asset to determine the assets with the best value added. Find the maximum, minimum, and average value-added score for each type asset across all missions, regions, and conflict states. Multiply the value added for each system times the number of systems in class B of that type system to determine the value added by purchasing that quantity of that type of asset. In our example, the minimum, average, and maximum values for type #1 are 0.010, 0.013, and 0.016; for type #2 they are 0.007, 0.0145, and 0.022; and for type #3 they are 0.01, 0.01, and 0.01, respectively. See Table 3.18.

Table 3.18

Minimum, Average, and Maximum Value Added

Class of System	System Type	Quantity	Minimum Value Added	Average Value Added	Maximum Value Added
A	#1	62			
	#2	39			
	#3	8			
B	#1	22	0.220	0.286	0.352
	#2	22	0.154	0.319	0.484
	#3	4	0.040	0.040	0.040

NOTE: See note on Table 3.15.

Plot the minimum, average, and maximum total value added for each asset type on a bar chart as the graphical basis. Look for dominance among the different assets to determine which assets provide the best value added across the scenarios considered. For ease of comparison, the assets may be displayed according to the following three rankings: largest to smallest maximum total value added (best performance), largest to smallest minimum total value added (least), and largest to smallest average total value added (most robust).

In our example, system type #3 is dominated by the other two system types and therefore should be ranked lowest in the class B systems. The comparison between system types #1 and #2 is not so clear cut. Although system #2 is better in terms of the maximum and the average, it is lower in the minimum case. In addition, system #1 appears to be more consistent than system #2 in both cases examined. This information may lead to a more detailed comparison of the two systems in each mission, region, and conflict state examined.

Note that the value added per item is not the only criterion to consider. Each *type* of asset contributes a fraction of the total score of the package. For any preferred package with that type of asset and all other types of assets held constant, any number of assets of this one type will contribute the same fraction of the total score. The reason is that we defined the score based upon the requirement for a given degree of accuracy for coverage 24 hours a day over the whole area of interest. If we were to define a package that does not meet these requirements, then the score contributed by that type of asset should be reduced. This may be done by changing the "allocation factor" in the "PrefMinPkg" (preferred and minimum package) spreadsheet to reflect a reduction in coverage by that type of asset. This assumption must be kept in mind when comparing the value-added score of each asset and the value-added score of each type of asset. Neither score alone tells the whole story.

A final consideration, not examined here, is the cost of purchasing the number of systems listed as class B. It may be that a cost-benefit analysis between the value added and the cost of the systems may lead to the best ranking of the system types in class B.

Since the preceding illustration was quite lengthy and detailed, it may be useful to summarize the process quickly so that its simplicity is evident:

- Review (and modify if necessary) the base CPFs;
- Select a scenario (region and conflict state), and define the environmental fractions (fraction of terrain closed, open, and mixed; and fraction of time weather is clear, hazy, or cloudy);
- Define the countermeasures multipliers (active and passive);
- Define the mission list and category multipliers for each mission and operational phase; and
- Select the minimum essential and preferred package for each mission.

All the remaining calculations described above are performed by the spreadsheets.

TEST APPLICATION OF THE STATIC MODEL

The OPVIEW project tested the static model as part of an effort to support the Army's MI 2000 Relook Task Force. In May 1991, the Deputy Chief of Staff for Intelligence asked the Arroyo Center to conduct a quick-turnaround, special assistance study to help illuminate and analyze some of the issues identified by the task force. The charter of the task force was to "review the intelligence and intelligence-related (e.g., fire support, communications, and counter mobility) battlefield operating systems and recommend ways to improve intelligence support to Warfighters." The DCSINT specifically requested that the Arroyo Center support its research with quantitative analysis using the OPVIEW methodology described in the preceding section. The study was conducted in two phases. The first phase was focused on generating issues for the MI Relook Task Force to consider for presentation to the Total Army Analysis General Office Steering Committee, which met in July and September 1991. In the second phase, both quantitative and qualitative techniques were used to assess the capabilities of intelligence organizations, processes, and systems to perform as an integral component of AirLand operations in multiple regions simultaneously (Bondanella et al., 1993).

In providing analytic support to this Army study, the OPVIEW project developed eleven combinations of conflict regions and conflict states (including five noncombat conflict states) intended to represent a comprehensive range of scenarios.

Combat	Noncombat
Honduras	Honduras
Israel-Syria	Israel and Persian Gulf
North-South Korea	North-South Korea
Eastern Europe, Poland-Russia	Philippines
NBC Crisis Response	Pakistan-India
Southwest Asia, Saudi Arabia	

The noncombat scenarios included peacekeeping missions, noncombatant evacuation operations (NEO), and low-intensity conflicts. Each scenario included a variety of terrain, weather, and countermeasures effects. The countermeasures included passive means, e.g., camouflage and electronic emission control, and active countermeasures, e.g., smoke and jamming.

To simplify the static nature of the model, the terrain, weather, and countermeasure effects were combined into degradation factors that would affect the ability of each type of sensor to perform the intelligence tasks listed in Chapter Two. Further discount factors were defined to account for the responsiveness of the sensor system's platform and the timeliness of the information provided by it. For example, missions during the planning and campaign execution phase tend to require faster feedback than do missions during the reconstitution phase. Discount factors were included by sensor type to reflect the effects of delays in information production and dissemination during time-sensitive missions. System responsiveness was represented by similar factors to account for any lack of intelligence results being given to Army commands when non-Army sensors were tasked.

Each scenario and mission also included from one to four operational phases that represented likely submissions during the operation. The static model was employed to discount certain intelligence tasks as a function of the mission. For example, targeting is not normally a task associated with indications and warning or peacekeeping. Discount factors were applied to each task performed by each collection platform. (See Appendix E for a discussion of data requirements and sources.)

For each phase, a preferred and a minimum essential package of assets was defined to accomplish the mission. Any synergism between assets, such as cross-cueing of UAVs by JSTARS, was assumed to be accounted for in the package description.

We examined systems in the current inventory and those that may be fielded within ten years, including Army, Air Force, and national collection assets. Among the newly fielded or developmental systems are radar imaging systems on aerial platforms, which have an all-weather capability against fixed or moving targets JSTARS, ASARS; the family of common-sensor signals intelligence systems on aerial platforms (GUARDRAIL for fixed wing and Advanced Quick Fix for helicopter) and on ground platforms (heavy and lightweight ground-based common sensor system); and the imaging systems on UAVs. Further, we did not limit our analysis to technical performance parameters, but we also examined the system connectivity architectures that are so vital in processing, analyzing, and disseminating intelligence to combat commanders in time to take effective action.

We believe that the static model, which uses a simple spreadsheet process, illustrates the phenomenon that any given system may dominate other systems in a particular task, but that a mix of complementary systems over the variety of tasks in multiple scenarios provides the balance needed by military commanders. The phased requirement specifies that the number of sensors cover at least a minimum area by each category (detect, locate, etc.). However, most individual sensors do not cover all categories well, especially after accounting for environmental effects. Since no single sensor is likely to meet all of the minimum essential requirements, a mix of systems would be required. Thus, the OPVIEW methodology can help demonstrate the need for a mix of systems, since no single sensor is likely to meet the range of performance required in each category. The analyst determines the types and quantities of sensors required for minimum coverage by an educated trial and error method, choosing among the sensors types available those types that provide the best coverage and building on them to make a set. In doing so he analyzes whether adding another sensor of a different type will provide more or better coverage than increasing the quantity of the same sensor type, and so on until he is satisfied he has arrived at the most capable mix. The CCPF tables help in making selections. The

analyst may not be free to choose what constitutes a minimum essential or preferred package. He may be constrained at the outset to use only certain types of sensors or be limited to a set quantity as conditions of his study. Therefore, by inference, the preferred mixes ought to result in better combat outcomes if they are evaluated in a dynamic simulation. (The static process can also be a valuable screening method before performing dynamic simulation.)

The scores for each system, given the two sensor package mixes examined, are illustrated in Figure 3.2 for the campaign planning and execution mission in the Korea combat scenario. The vertical axis shows the maximum score (8) that could be attained by a theoretically perfect system performing intelligence functions within eight categories (detect, locate generally, locate precisely, classify, track, acquire as a target, identify, postattack assessment).[6] The height of the bar for each system indicates the best that could be expected in a benign environment, primarily based on technical performance criteria. The scores of the smaller bars represent system capability when considering how environmental operational factors (weather, terrain, enemy countermeasures) affect the accomplishment of the combat missions. The reduction in capability resulting from operational factors (terrain, weather, countermeasures) is shown in this chart to be a factor of 2 or 3. The main reason for this is

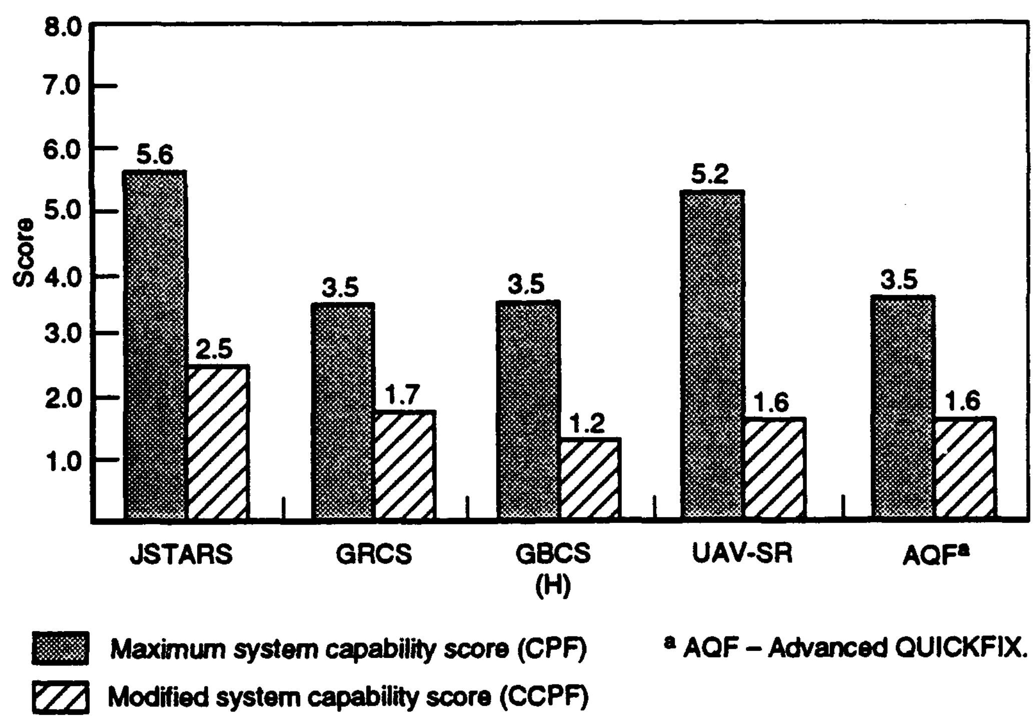

Figure 3.2—System Scores for Campaign Planning and Execution Missions in Korea Combat Scenario

[6]In this case, we used a row sum as a measure of asset performance. There are many ways to combine scores, depending on the application.

the extreme terrain variation in the Korean theater that reduces line-of-sight coverage for most types of sensors. In the case of lightweight UAVs, the reduction was also caused by stormy weather, in which the platform could not fly.

The multiscenario assessment (Figure 3.3) shows that the tactical airborne radar imaging systems (JSTARS for moving targets and ASARS for stationary targets) are extremely valuable in scenarios characterized by large-scale military conflict (Europe/Southwest Asia) and for the NBC crisis response mission, where large, denied areas need to be covered rapidly and comprehensively under the most adverse environmental conditions. The other systems operate in a highly complementary fashion, as evidenced by the close range of values across combat and noncombat scenarios (the horizontal bands shown in Figure 3.3). Although in this illustration JSTARS and ASARS are higher valued individually, their values were achieved within a particular mix of other IEW/TA systems in which combat commanders required the other systems to do more precise planning and execution on a continuous basis for all four missions.[7]

Looking across all scenarios and missions, we concluded that the balance among current IEW/TA systems was sufficient for the 1980s, when a more linear battlefield was expected, but that there needs to be a different balance among the intelligence

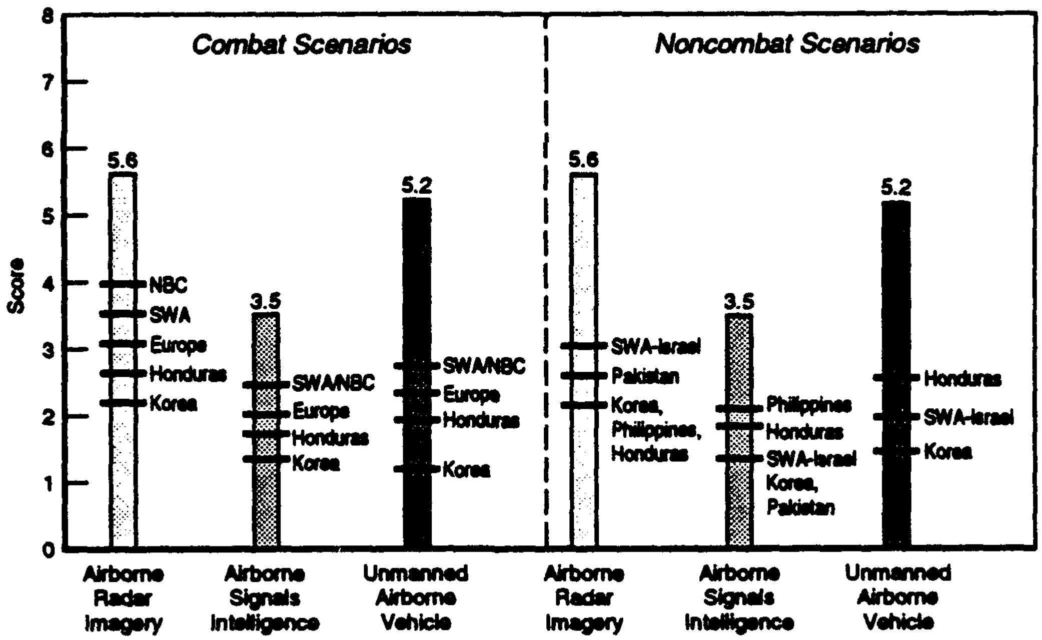

Figure 3.3—Operational Effects on Collection Systems Across Combat and Noncombat Scenarios

[7]We consider it important to include whole packages. The values for IEW/TA packages in this analysis are used mainly to illustrate the process.

functional areas to perform as an integral component of future AirLand operations, which are expected to be more dynamic and nonlinear.

We observed that there is an almost equal value-added score for each IEW/TA system in the preferred and minimum mixes we examined. This does not represent redundancy or duplication; rather, it highlights the fact that each system was better suited to overcome some particular aspect of the environment (e.g., weather, terrain, and potential enemy countermeasures) in performing specific tasks (e.g., detect, locate, and identify) required to successfully accomplish different missions.

SUMMARY

Benefits of the Static Model

- Rapid setup time, permits quick results of many different cases;
- Can serve as a screening tool before using the dynamic operations simulation model;
- Provides outputs that are adequate for first-order program decisions when the need for sensitivity analysis is not indicated; and
- Requires little training to use compared with more complex models, such as the dynamic model.

Limitations of the Static Model

- Provides situation dependence between scenarios, but not within a given package, mission, and scenario;
- The required input values are subjective, therefore, a highly disciplined process is required to deal with uncertainty; and
- Does not represent value to the decision process concerning outcomes (combat or noncombat).

Prerequisites of the Static Model

- Requires adequate background in intelligence capabilities and military operations;
- Requires identification and analysis of outputs to determine key issues; and
- Requires a sufficient number of package combinations, missions, and scenarios to provide adequate analysis for robustness.

Future Uses for the Methodology

The methodology, which we envision being used at both the Army Staff and the U.S. Army Intelligence Center, should prove useful to other government intelligence agencies. It provides a disciplined approach to making necessary resource allocation

decisions. When combined with analysis of economic production, manpower programs, and the total military force to be supported, the methodology could provide acquisition managers and decisionmakers with a clearer and more substantial basis for structuring and enunciating the benefits of their programs for the DoD Program Objectives Memorandum and for the Presidential Budget submission to Congress.

Chapter Four

APPLYING THE METHODOLOGY USING THE DYNAMIC MODEL

The dynamic model was developed as a simulation to support the time-dependent analysis of military operations. It is narrower in scope than the static tool but provides more detail. Its principal use is to reflect the dynamic interactions between the commander's decisionmaking process, his current plan, collection means (i.e., the sensors), and their ability to support the current plan as it unfolds (or unravels, as the case may be). The dynamic model provides two-sided simulations, with different perceptions of the conflict arena stored by each side, as well as the "ground truth" in the model.

The dynamic model requires detailed inputs, including a map of the terrain, the forces available to each side, a mission statement, the plan of each side to accomplish its mission and objectives, and the sensor allocation scheme to support each side's plan. Unlike the static model, which defines an average situation, the dynamic model reflects the ability of a sensor to accomplish a given intelligence task in a specific type of terrain and visibility, and against specific countermeasures that are currently being used by the enemy.

To save development time and costs, a version of the RAND Strategy Assessment System (RSAS) was modified into the RAND Analytic Modeling Platform (RAMP) to provide a modeling environment. The dynamic model was inserted in the RAMP simulation shell. When the MAPVIEW[1] graphics capability became available, the OPVIEW simulation outputs were incorporated in MAPVIEW graphics displays.

The model uses the UNIX operating system, and RAND-ABEL® computer language. The current prototype can be run on a Sun computer with 600 megabytes of memory.

MODEL DESIGN ISSUES

The traditional design process has two phases. Models are first designed and then implemented to the design specifications. The two-phase process is applicable when the subject of the model is well understood. However, if the subject is not well understood, the two-phase modeling process no longer applies. Since the best design is not known at the start, the very process of building "models" leads us to a design approach of simple and useful models.

[1]MAPVIEW is a graphics tool, developed at RAND, that can be used mainly to illustrate the movement of icons along mobility corridors and terrain cells. It is a graphics tool for illustrating simulation objects overlayed on a background of terrain features or coverage laydowns.

As a result, the dynamic model had to be designed and built with a high degree of flexibility in mind.[2] Briefly, the modeling environment is designed to be used as an experimentation platform so that different proposed designs can be tested for their applicability and efficiency with respect to measuring the value of intelligence.

During the course of this study, we examined many different model designs, most of which were discarded. The latest design shows promise of an appropriate level of detail and applicability. However, the efficiency of the current prototype is slower than necessary because arrays rather than linked lists are used. With arrays we must currently track all of the locations on a map of the conflict area where nothing is occurring at the same level of detail as the locations where something is occurring. With linked lists, the analyst will be able to be more selective in what is stored in the model and how he searches through the data structure. See the discussion below on short run times for a more detailed discussion of this issue.

The development process was greatly facilitated by the use of the RAND-ABEL language, as described below. The table structure of RAND-ABEL allows those with limited or no programming skills to quickly see the key issues in the model. In addition, there are no hard-wired numbers in the model, since the code can be modified even during a run without compiling. As a result, significant redesigns of the model can be performed in a day or, at most, within a week. In addition, the model can be either deterministic or stochastic in any functional area, depending upon the model designer's and model user's needs.

The RAND-ABEL Language

The RAND-ABEL language was developed as part of the RSAS development program (Shapiro et al., 1985, 1988). RAND identified the need for a language that could represent decision processes in an understandable, flexible, and rapid manner. RAND-ABEL is a procedural language that is parsed into C-code and then compiled into machine language. This makes processing time relatively quick—no more than three times slower than normal "C" code, depending upon the number of files being interpreted. The RAND-ABEL "interpreter" is a process that selectively interprets only those files modified by the analyst between compilings. Although interpreted files take longer to run, the increased run time is more than offset by the ability to change selected portions of the model without compiling.

Probably the strongest feature of the RAND-ABEL language is its extensive use of tables. Originally designed to describe an automated player's decision process in a simple, tabular form, this structure has since been applied to a large number of the model's databases, including the assessment processes.

Table 4.1 shows an example of RAND-ABEL code. The input variables are the five variables on the left side of the table. The output variable is on the right. It is possible to have a very large number of input and output variables, but for ease of viewing by the user they are usually limited to what can be seen on a screen or a standard size sheet of paper.

[2]This kind of "highly interactive" modeling environment is described in more detail in Bankes et al. (1992).

Table 4.1

Decision Table Showing Degree of Intelligence on Enemy Units

Detect	Locate Generally	Locate Precisely	Classify	Identify	Degree-of-perception
>0.90	>0.85	>0.80	>0.75	>0.75	ID
>0.85	>0.7	>0.5	>0.75	—	Type
>0.80	>0.5	>0.75	—	—	Size
>0.80	>0.75	—	—	—	Size
>0.75	—	—	—	—	Detected
—	—	—	—	—	Undetected

In this example, we attempted to determine the degree of perception that can be obtained about enemy units. If the coverage in each of the first five intelligence categories meets the specified criteria set by the analyst for his study or received from a higher authority, then the enemy unit will either be undetected, detected, only the size known, also the type known, and, finally, the identity known.

The first row reads as follows: If the detection coverage is greater than 0.9, and the coverage to determine general location is greater than 0.85, and the coverage to determine precise location is greater than 0.8, and coverage to determine classification is greater than 0.75, and the coverage for identification is greater than 0.75, then the unit is considered as identified. If the above conditions are not met, then the code assumes an "else" statement, and checks the next row for its conditions to be satisfied. Note that in the second row, we are not interested in what the coverage for identification is, as denoted by the "—" symbol. Each row is examined until the first row that satisfies the conditions is found.

Once the degree of perception of the unit has been determined, this information can be displayed in the blue-perception (of Red and Blue) graphics on MAPVIEW. An undetected unit is not shown. For a unit that is only detected, the screen displays an empty (Red for opposing forces) icon that indicates that something is there, but what type unit, or how large it is, is not known. A unit whose size is known is displayed as an icon with the unit's size mark (such as an "x" for a brigade) on top of the icon. A unit whose type is known has the unit type symbol also displayed within the icon. Finally, if the unit's identity is known, its identity is displayed beside the icon. The color figures in Appendix B illustrate some of the kinds of MAPVIEW outputs of the dynamic model.

The analyst can change any of the values in the table, add new rows to the table, or add additional columns of new input or output variables, even while the model is running, through the RAND-ABEL interpreter. This allows the analyst to selectively increase the resolution of this assessment process interactively.

Note that the RAND-ABEL table structure makes it relatively easy for nonprogrammers to understand the model in sufficient detail to know whether or not they agree with the design, and where it may need to be modified. Note also that with this structure, new data may be added to the tables, even while the model is running, so that additional detail may be added during the course of analysis.

Short Run Times

Another virtue of the model is that the data used can be highly aggregated so that computer runs can be made in a short time. Currently, the model runs at a 12:1 time compression for a SWA scenario with our two Red and Blue corps resolved to brigade-sized maneuver units. Setup and table selection preparation and display of the graphics require additional time.

Since the model is fast running, the analyst does not have to wait long for results. He is able to gain insights quickly and is apt to work more freely with the model than he would if it took many hours to see results and change direction. (For example, an analyst can run a day of the model in two hours, analyze the results for another two hours, change the model in an hour or less, and run it again.) With high-resolution-only models, setup time may take several weeks and run several hours, and evaluating results often requires several weeks. This tends to inhibit the analyst from performing a number of sensitivity runs, whereas a model that can be run quickly tends to promote more extensive use.

One main benefit of aggregating the data is to provide for fast computer runs, and it also unburdens the analyst from having to interact with data that he already agrees with and is contained in tables that can be easily changed when desired. However, for the data to maintain credibility, the analyst must be able to quickly inspect and decompose any of the data to check or change any value. Once he agrees with the values and rule sets in the model's tables, they remain in effect until changed. The analyst may accept and use them as defaults, copy them over to another region or theater with associated operational vignette, make changes to suit particular environmental and other conditions in new contents, and run them in other cases. This can greatly help reduce the setup time for successive simulation runs.

For rigorous analysis, a number of sensitivity runs can be made that focus narrowly on particular aspects of a study or issue. For this, the analyst may wish only to scroll through the tables and data elements that pertain to specified areas he does not wish to change, for example, the type of conflict, region, mission, operational plans (OPLANs), IEW/TA employment doctrine, or other rules. He might search for possible effects resulting from different mixes of IEW/TA systems in the same operational setting each time he makes a run.

Deterministic and Stochastic Features of the Model

The model is mainly deterministic, although it has some stochastic features. For example, weather effects and attrition of sensor platforms can be either deterministic or stochastic. In the deterministic mode, the probability of killing a platform or a sensor system proportionally reduces its coverage. In the stochastic mode, the sensor platform either survives or does not as a result of a computer's pseudorandom number generator. The probability of being killed is a function of the enemy threat to the sensor system at a given time and place. In the beginning, the analyst selects which modes and which version he wants to use as inputs for a model's run.

DYNAMIC MODEL ANALYTIC APPROACH

The dynamic model provides a simulation environment into which the analyst can put data that are relevant to what he wants to study, and helps him keep track of their

interrelationships so he can investigate causes and effects and draw inferences from them.

The model can help the analyst develop insights by asking "what if" questions. It narrows the search for a preferred mix of IEW/TA assets or characteristics. The selection of a desired mix for program decisions is based on expert military judgment using the modeling framework and may be compared with outputs derived from a fixed-function model. Flexibility is achieved by a structure that the analyst can readily change by choosing various tables in the model, modifying the default values in them, or adding new tables.

A model simulation case begins and ends with a mission statement (see Figure 4.1). The case describes operations planning steps, then proceeds with the development of intelligence requirements (i.e., commander's information needs) followed by adjudication of either combat or noncombat outcomes, depending on the type of study and scenario. This adjudication determines whether they fall above a level of significance, set by the analyst. The scoring process is used to relate IEW/TA performance characteristics (CPFs, described in Chapter Two) that are modified by the environmental and operating constraints for each region to the intelligence requirements (decomposed into PIRs) for each mission. The modified capabilities are the CCPFs. This method is used to evaluate intelligence performance before, during, and after operations. (As mentioned in the description of the static model, the CCPFs reflect the likely results given a time-independent situation (e.g., averaged over time). By contrast, in the dynamic model, the CCPF is a function of the specific sensor looking at a specific unit in a given type of terrain, with weather and countermeasures applicable to that specific situation.)

Throughout the process, the analyst can maintain a vision of operations planning and management issues and possible operational outcomes in various scenarios that

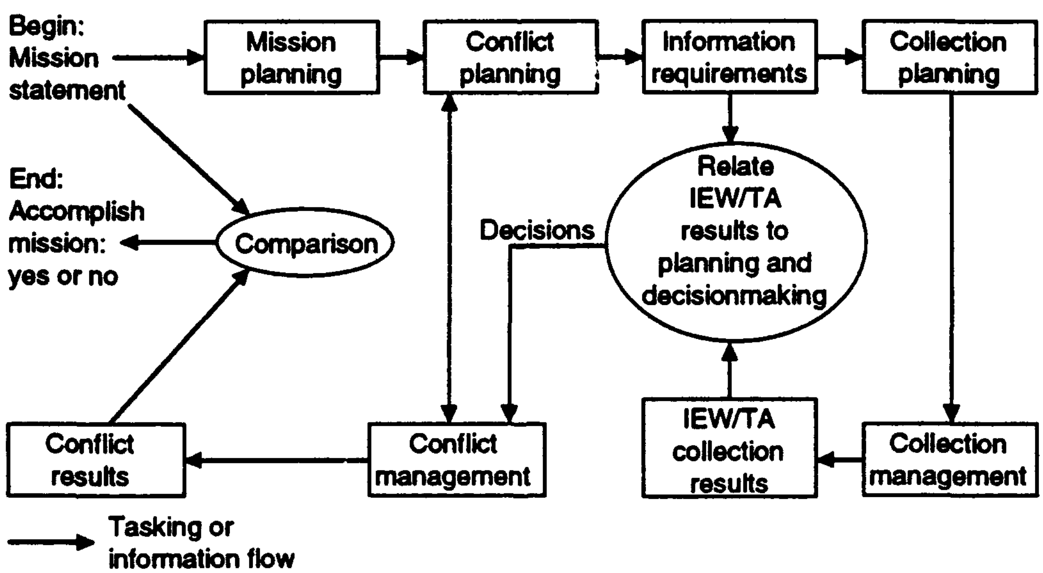

Figure 4.1—The Dynamic Model Supports the Entire OPVIEW Analytic Framework

can affect accomplishment of the mission. One of the most important benefits to be derived from the use of this model is an understanding of the relationship between IEW/TA results and planning and decisionmaking, both in terms of the quantity and quality of information and its timeliness to the decisionmaker.

Credible measures are available that can be used to attribute the results of applying force in combat or noncombat military operations. For example, one could adjudicate the results of units deployed on selected axes, types of engagements, number and types of targets attacked, objectives reached, and missions accomplished. Among other things, these measures depend on operational planning, various ways forces are employed, and the availability of information about the setting, environment, and own forces and their capabilities, as well as enemy capabilities, intentions, and operations.

Input values to the model are key to this approach. Tables have been generated, which are intended to capture the full range of expected values, although it should not be necessary to use all of the tables during every simulation run.[3] These tables are intended to cover the more important areas that are required for performing typical IEW/TA system value analysis, and more lines of code can be added to the tables if needed. The model's flexibility allows the analyst to readily change any of the values in the existing tables or incorporate entirely new and even different tables.

The values used in all the tables are derived from an understanding of physical phenomena, and system operational performance from military subject matter experts. The sources of the values, rules, and other data in the tables are recorded and dated in file notation rules that accompany each table. This is done so the analyst can check any of the table's data to determine its source, relevance, and information currentness. It is important to note, however, that the user is free to change any value in any table at any time he chooses. None of the values is considered "sacred" and nothing is hardwired. Appendix G outlines a plan for assessing the validity of such judgments.

SETTING UP THE DYNAMIC MODEL

Since the world's political and operational settings are always changing so dramatically, the OPVIEW research team worked with the Army to help decide which regions, scenarios, operational vignettes, and IEW/TA systems the Army wants to study and in what order. The OPVIEW project developed a database of operations vignettes (which will be published separately) derived from a variety of scenarios depicting operational-level plans, e.g., corps and above. Operational vignettes are useful for illustrating how IEW/TA systems perform in more than one region, geographic setting, and operational circumstance. Thus, the analyst may vary force deployment contingency plans that are operationally flexible. The relevant aspects of the operations vignettes are to:

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[3]Even though many tables will be available for the analyst to choose from, only one of a table's lines of code at a time is used from each selected table, so run time for even as many as twenty tables would be brief. Appendixes B, C, and D contain several illustrations of tables employed with the model and some of their uses.

- Represent approved scenarios or new candidate scenarios;
- Depict engagements between opposing forces (for either combat, noncombat, or mixed missions);
- Illustrate important conflict dynamics and key results;
- Provide visual representations of Red and Blue:
  - — Concept of operations,
  - — Operational plans, and
  - — Order of battle and scheme of maneuver;
- Give ground-truth of the initial and phased locations of opposing forces, plus their support elements;
- Designate IEW/TA system types, quantities, and their employment plans; and
- Provide modeling structure in which the analyst can enter operational and IEW/TA parameters in the model to verify the model's default data.

Within a given scenario the analyst can then further explore the relationship between operations, information needs, and IEW/TA systems using alternative collection-management techniques. Such techniques require interaction with the commander's planning process. In the decision submodel, this is represented by statements derived from OPLANs and concepts of operations contained in the operations vignettes. Typical statements include the mission and key objectives, plus assumptions and limits, as well as mission-derived information requirements. The non-intelligence battlefield operating systems are considered in the development of the concept of operation and scheme of maneuver. We highlighted the intelligence systems, since that is what is being analyzed. The other battlefield systems are considered when determining the starting values for the intelligence systems, e.g., targeting, tracking, and accuracy. These other battlefield operating systems form the basis for the PIR and HPT information for the decision sub-model, as depicted in Figure 4.6. Since this is a two-sided methodology, the information must be generated for Red and Blue. For example, the following scenario information should be provided at the start of a model run:

- Regions and scenarios to be studied;
- Major terrain features and obstacles on the computer's digital map;
- Stated or assumed objectives;
- Day of conflict, time of day at start, and estimated conflict duration;
- Opponent's starting postures and locations;
- Planned force locations in subsequent phases;
- Routes that units might travel to reach their objectives (note that since the model is both dynamic and interactive, these are expected to change frequently during the course of a run);
- Commander's criteria for mission accomplishment and plan changes;
- Weather conditions for the entire region or for specified areas within th[illegible]n;

- Specific intelligence requirements; and
- Sensor allocation schemes.

The mission-derived information requirements, i.e., commander's information needs, include more than intelligence information. Therefore, the analyst must refine selected subsets to prioritized intelligence requirements as well as requirements for collection under weather effects and against high-priority targets.

After completing this part of the setup process, the analyst then structures the intelligence support for a given plan.[4] The analyst should verify that the following data in the model are applicable in the scenario being examined:

- Locations, patterns, and dimensions of IEW/TA coverage;
- Requirements criteria for specified sensor coverage and total times to meet initial operational requirements;
- Mission requirements and parameters, e.g., desired area coverage and system performance capabilities, to detect, locate, identify enemy assets, for example;
- Employment plans, e.g., distance from base to forward operating areas or a FLOT, operating locations, sensor platform orbit parameters, revisit times, standoff distance, depth of penetration forward of each FLOT; and
- System responsiveness and survivability parameters.

During the course of a model run, the analyst may need to modify the plan or the sensor allocation on each side to support the objectives of the analysis. The following factors may be modified by the analyst during the course of a run:

- The decision to continue on the same plan, modify it, or choose a new one;
- Subsequent modifications of intelligence requirements, collection planning and management, and plan execution;
- Desired coverage to meet PIR, IR, and HPT criteria.
- Total times according to system connectivity network architectures;
- Modification of system packages for collection;
- Computation and analysis of the capability of packages to meet criteria; and
- Sensitivity analysis:
  - Analysis of simulated coverage to meet criteria,
  - Analysis of total times according to system connectivity architectures, and
  - Analysis of effects of intelligence coverage and reporting times on decision-making and plan changes, operations outcomes, and mission accomplishment.

Obviously, the number of choices available to the analyst is very large. The degree of flexibility is intentional so that a great variety of simulations are possible without

[4]The setup process needs to be performed only at the beginning of the analysis and the defaults may be used repeatedly, with few or no changes, during subsequent sensitivity analysis and trials. Most at the system-level data (range, coverage pattern, etc.) are already in the model.

constraining the analyst's freedom. Nevertheless, such a wide range of choices can also be bewildering to a first-time user who must first gain substantial experience and understanding about how the model works and how to use it. The approach we recommend is to limit the number of sensors to just a few in the beginning, then expand the types and increase the quantities, then vary the environmental settings only after sufficient confidence has been developed in using the model.

OVERVIEW OF COMPONENT SUBMODELS

There are three main components to the dynamic simulation model: the decision submodel, the intelligence submodel, and the operations adjudication submodel. To understand the overall model design, the analyst must understand the three basic submodels making up the dynamic model system, because of the close relationship between these submodels, both in terms of how they represent the environment and how they communicate with each other. A highly simplified diagram of this relationship appears below. Each component model is described in Figure 4.2, first briefly and then in more detail. Additional documentation for each is provided in Appendixes B, C, and D.

The Operations Adjudication Submodel

The operations adjudication submodel uses a grid-square terrain map (currently 10 km on each side).[5] The grid can be thought of as the model's "gameboard." The analyst can keep track of a number of attributes on each square, such as terrain, forces, and collection assets present within the associated geographical area. The model does not represent geographic information within a square except as it affects these measures (e.g., it is not possible to determine whether more forces reside in one half of the square than in the other). This level of resolution is maintained throughout the other submodels.

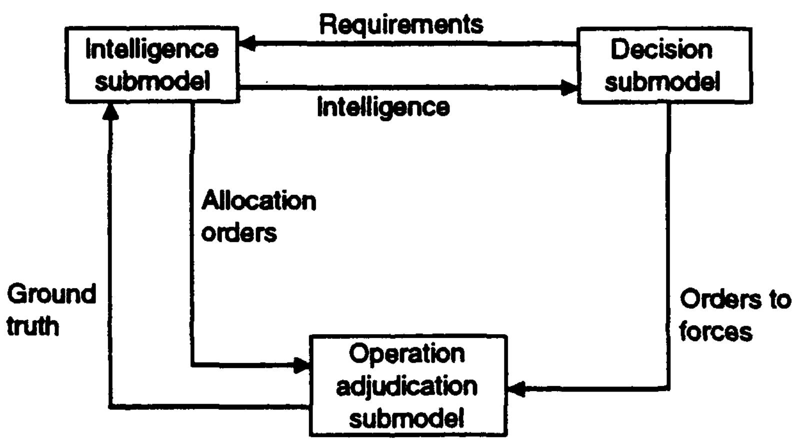

Figure 4.2—The Three Main Component Submodels of the Dynamic Model

[5]This size corresponds with a 1:250,000 map, which is typically used for corps and EAC planning. This size map is not a limiting factor.

The movement of forces and assets are all simulated within the operations adjudication submodel. It is a time-step model that processes at once all events occurring during a specified amount of simulated time (currently, one hour). The result of each time step is called "ground truth." The various forces and assets modeled by the operations adjudication submodel are set in motion by "orders" received from the decision and intelligence submodels. The inputs to the operations adjudication submodel are the "orders" to forces and collection assets; the output is "ground truth."

The Decision Submodel

The decision submodel is the place where commands are executed in the dynamic model. We refer to the model as being "semiautomated," since it is designed to cover only those possibilities specified by the analyst. The software will request analyst intervention whenever a situation occurs that the analyst did not initially foresee. This is not to say that it is incapable of modeling surprise and deception, only that the *analyst* must anticipate the situation, *not* the simulated "commander." This distinction is important to keep in mind; we call it the "God's-eye view" as opposed to the "commander's view" of the situation. The difference is those enemy units that are actually present versus what the commanders' intelligence-collection results report about each side.

The analyst's input to the decision submodel is called "plan segment set." This is sometimes referred to as a "plan," but such usage might lead to confusion with operations plans. It is produced from an operational plan but is more explicit in terms of how it specifies the orders to be issued and the timing and conditions under which they are valid. Each course of action and the associated conditions for that course of action is called a "plan segment." A plan segment can be thought of as a set of connecting paths with rules specifying which path may be chosen and at what time.

For example, assume that at a given point in an operation, a commander chooses to counterattack with reserve forces (a continuation of the current plan) or to retreat. Which possibility he chooses depends upon the status of his forces, various physical factors (time, weather, terrain, etc.), and what he knows about the enemy's forces. At this time, there are three plan segments to choose from: the current plan, the plan when things go wrong, or the contingency plan for new opportunities. In this case, the decision submodel will have three sets of rules, one for each course of action, and will periodically compare the current situation against those rules to determine when a transition needs to occur. A fourth set of rules (called limits) determines when the current course of action is not valid. If such a limit is reached, the model comes to a halt, at which point the analyst can insert a new rule set and course of action.

Intelligence is a major component of the rules that determine decision submodel behavior. The decision submodel has no direct access to enemy ground truth. It must base all of the conditions in its rules on known physical factors, its knowledge of its own forces, and the perception that the intelligence submodel provides of enemy forces and their activities. This means that intelligence can have a significant effect on the decision submodel's behavior and ultimately on the decisionmaker's decisions. Going back to our reference to "God's-eye view" and "commander's view," we see that it is entirely possible for the decision submodel to be "surprised" because it did not receive crucial intelligence in a timely way or was otherwise deceived. In addition, it can be seen that insufficient information can also prevent the selection of a

course of action for exploiting an opportunity. We will discuss decision submodel rules more extensively as we examine the intelligence submodel.

The Intelligence Submodel

The intelligence submodel reflects the ability of a sensor to accomplish a given intelligence task in a specific type of terrain and visibility and against specific countermeasures that may be employed by enemy units. As indicated above, sensor assets may be attrited in a deterministic (fractional losses) or stochastic (loss or survival as a result of a computer's pseudorandom number generator) manner, depending upon the analytic requirements.

In addition to the terrain map, the dynamic model also displays a "coverage" map, which indicates the degree of detection coverage then currently available in a given 10 × 10 km grid. Assets that cover less than that in a one-hour time step proportionally contribute a fraction of their full coverage in that small area. As sensor assets move, the coverage maps automatically change. Visibility factors degrade coverage, depending upon the type of asset and the environment.

The degree of coverage by intelligence task is stored for each unit (both friendly and enemy). The ability to determine the information gathered on the unit is a function of its passive countermeasures and the degree of coverage for each intelligence task. For example, a unit that is stationary will not be detected by JSTARS. If it has employed camouflage, the degree of detection by visual-frequencies band IMINT sensors will be reduced. If there is sufficient information in each intelligence task category, the enemy unit may initially be perceived by the friendly side as either undetected, detected, only the size known, the type of unit also known, and, finally, the identity of the unit is known.

If an enemy unit is in a target area of interest, it may be engaged by friendly fire support assets only if the coverage in the TAI is current and sufficient for acquiring targets. The greater the acquisition coverage, the higher the number of assets in the TAI that may be attacked. Similarly, the greater the ability to currently perform operational status assessment (or poststrike battle damage assessment), the greater the ability to report the actual number of enemy assets destroyed in the attack.

There are two representations of information timeliness in the submodels. The aggregate representation of timeliness used in the static model employs discount factors to reflect that assets with real-time collection capabilities are very useful for targeting, whereas assets with near-real-time collection capabilities are slightly degraded, and longer-time collection capabilities are significantly degraded for tracking and targeting tasks. For the dynamic model, a more explicit representation of timeliness could track intelligence data over time so that the effects of timeliness may be analyzed in more detail, which also allows for the representation of intelligence inferences and deception. For example, if an enemy unit is stationary, no other similar units are in the area, and the unit was identified within the last hour, then, by inference, the identity of the enemy unit should be known in this hour as well, even if only the presence of the stationary unit was detected. Although this process is not yet active in the current dynamic prototype model because of the large memory and computation time requirements, it can be added by the Army, or RAND, employing linked lists rather than only the array data structures currently in place.

Next, we will examine these three submodels in more detail, beginning with the decision submodel.

DECISION SUBMODEL

Overview of the Decision Process

The commander develops his concept of the operation and estimate of the situation for his selected plan. His estimate reflects his initial estimate (provided by the analyst) and successively updated estimates (provided by the model) of Red ground truth.

The commander's information needs (IRs, PIRs, HPTs) are derived from his plan and are inputs for tasking the Intelligence Preparation of the Battlefield (IPB) process. In accordance with his information requirements, intelligence assets are employed to obtain updated estimates of Red ground truth. The result of this process is an updated estimate by the G2, G3 staff, of ground truth, which is governed mainly by the types and mixes of intelligence assets, the local environment (including the effects of terrain, weather, and countermeasures), plus Blue's doctrine of IEW/TA employment and Red's force employment doctrine. Figuratively speaking, the resultant estimate is given by his staff to the commander who compares it with his initial or latest estimate. The commander then decides whether or not to continue to execute the selected plan, to modify it, or to choose a different one.

To test for feasibility of continuing the same plan, the commander makes decisions and issues orders for the operation's execution. Results of movement and combat are adjudicated, which may affect Red ground truth. If they do, this provides a revised estimate of ground truth and resultant operations outcome, which affect future orders and can be used to evaluate mission accomplishment, or the lack thereof.

Figure 4.3 illustrates a process, implemented by the decision submodel, wherein the analyst can decide whether or not a plan, if executed, would produce planned, catastrophic, or opportunistic outcomes. When the plan reaches the first decision point, it compares the conditions as perceived in the conflict area to the decision criteria. If the situation exceeds set thresholds, the plan is considered to have failed catastrophically and a new plan is selected. An example of a catastrophic event is that the enemy approached from an unexpected direction. Alternatively, the enemy may have made a mistake, and the plan could recognize that an opportunity exists. This event would also allow for a change of plans. In most cases, the decision would be to continue the plan with modifications, since there is apt to be inertia in a corps-sized operation. Unless the situation deviates significantly from the plan, the plan will be followed. This process is repeated at the next decision point (either time or event driven) until the plan is completed or changed.

The following subsections will discuss details of the requirements for planning, plan selection, and plan execution.

Requirements for Operational Planning and Execution

Information and intelligence are needed for both planning and executing operations. Both of these functions are usually performed simultaneously employing many of

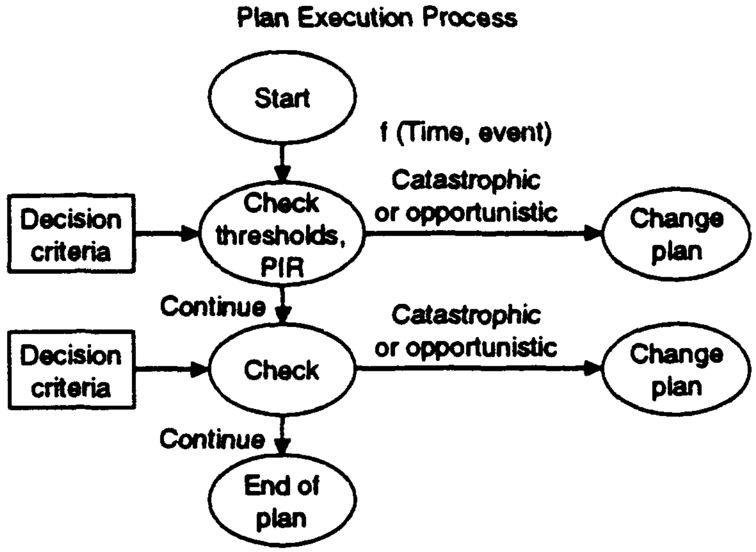

Figure 4.3—Decision Submodel

the same assets, although the output from sensors and processors, data links, etc., that are tasked to support planning often contribute to operations at a future time, whereas those that support conflict execution usually operate in current time.

For planning purposes, the commander asks: "What information and intelligence do I need to plan a forthcoming operation?" For execution purposes, he may ask: "Given that I am on this plan, what information and intelligence do I need to execute it?" These two questions can give very different results. For planning purposes, the emphasis is likely to be more on the availability and status of friendly forces, the identification, location, and status of enemy forces, weather, terrain, situation development, and target categories. For conflict execution purposes, the emphasis is apt to be less on situation development and more on friendly and enemy status updates, target development, target acquisition, and postattack operational assessment.

Plan Selection

As shown in Figure 4.4, the analyst provides one or more candidate plans to evaluate, each with his initial or current estimate of the enemy situation, plus his criteria for selecting or rejecting each plan. The criteria for evaluating the likely success or failure of a plan can be organized according to the mnemonic acronym METT-T, namely,

- Mission and possible restrictions;
- Enemy dispositions, equipment, doctrine, capabilities, and probable intentions;
- Terrain and weather;
- Troops available, i.e., friendly forces to execute the plan; and
- Time available to execute the plan.

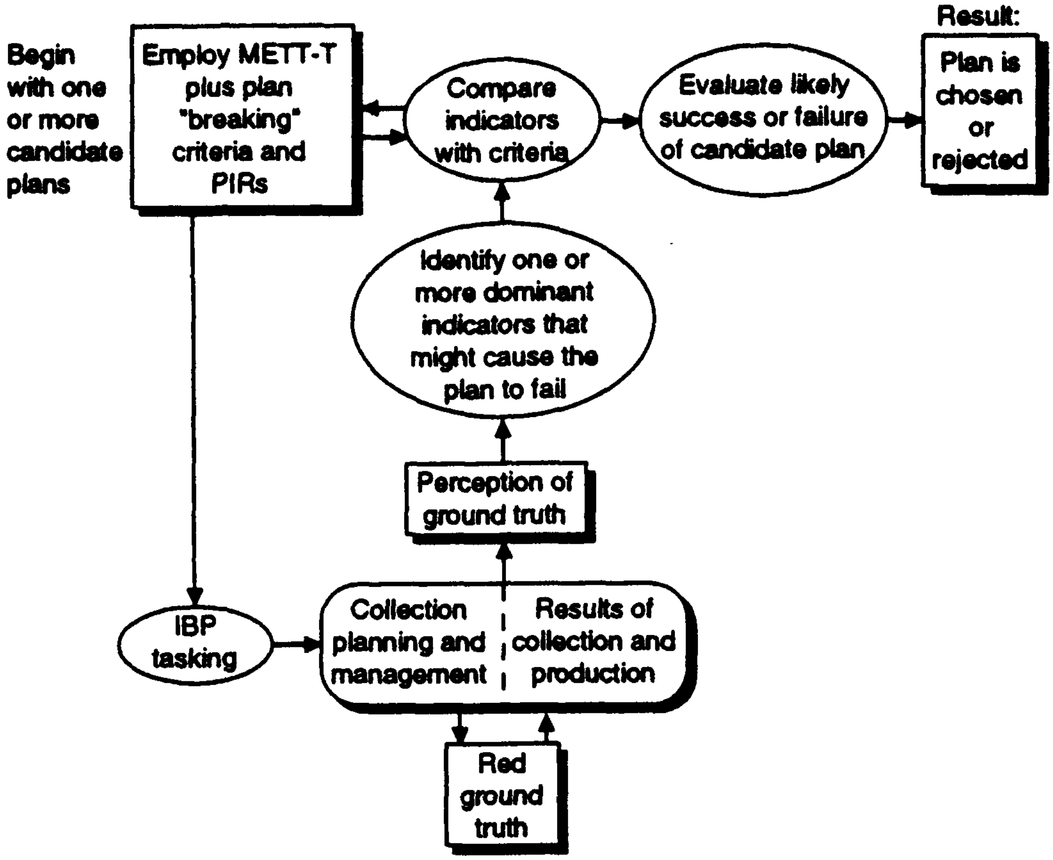

Figure 4.4—Choosing a Plan: Relating Intelligence to Planning and Decisionmaking for Plan Evaluation

Plan Screening

The analyst may ask, "Given one plan, which component of the enemy situation could prevent this plan from being successfully executed?"

Any single METT-T factor might be a "plan breaker," in which case the remaining factors need not be considered to further evaluate the plan. In this case, however, we are concerned only with the enemy situation. The analyst need only determine, from a set of intelligence factors, if there is one factor that would prevent the plan from being successfully executed.

For this analysis, the intelligence picture does not have to be comprehensive or highly detailed if a single controlling factor can be found that would dominate the operation's outcome. Therefore, it should *not* be necessary to integrate all of the available information and intelligence from multiple sources, since discrete inputs can be handled independently.

For example, the G2 might report that a large enemy force (much larger than was considered in the commander's initial estimate) would be close enough to the area of operations to advance in time to influence the battle at the time the plan would be executed.

Discrete pieces of information and intelligence from various collection sources may be used to evaluate a plan's success as long as they satisfy the commander's criteria for the necessary and sufficient conditions about the enemy situation. These can be treated as independent factors and need not be combined with all of the other enemy situation data. Thus, if there are no significant negative (to Blue) conditions in or near the area of operations, the plan may be considered as reasonable for execution.

Area of Interest. Intelligence systems would be mainly focused to gather data in areas of interest and operations. For the plan evaluation, the ground area of importance tends to extend well beyond the areas of operations that are the commander's principal focus during plan execution. Consequently, intelligence systems in the model are also oriented on particular areas outside the commander's main battle area (i.e., his areas of interest), to provide information about the enemy situation that helps him evaluate the plan's likelihood of success or failure. Major external conditions in the immediate vicinity around the main battle area would be evaluated along with those that could influence the battle's outcome within the main battle area. When thresholds set by the analyst are exceeded, the model's software automatically alerts the analyst or "warns" him of impending danger to the successful execution of his plan.

The model is used to identify, locate, and track enemy units, according to events and to record the times of those events, with the aid of multilayer computer maps that are registered and have rows and columns to indicate paths of the movements of both Red and Blue forces. The locations of forces and their activities can be independent or connected. Thus, contiguous linear battle formations are not necessarily represented when they are inappropriate for a given study. Indeed, totally separated conflict areas may be represented, with different area sizes, missions, forces, and conflict intensities.

Information Requirements. For planning, large area overview information and intelligence-gathering systems are applied mainly to such intelligence functions as indications and warning, and situation development, while much narrower "viewing" systems are employed for target development, target acquisition, and battle damage assessment. Such questions as, "When and where will the enemy attack in my sector, or area, and in what strength?" are typically asked before evaluating and choosing a plan. The former groups tend to be dominated by events related to force type, size, movement, and timing with relatively few requirements for specific information about a unit's identity or its activities. The latter group is focused more on smaller units and specific types of equipment.

Adjudicating Alternative Plans. Given the remaining set of possible plans for this scenario, the analyst should examine each in sequence. Operations adjudication can be employed to measure probable outcomes to test the utility of each plan being evaluated. Expected operational outcomes can be measured so that important inferences can be made about the utility of particular intelligence systems and their mixes, which provide information and intelligence limited to those intelligence functions. These results can then be compared with those obtained from evaluating other plans with the same mission and objective to determine which ones would be more likely to succeed or fail. Note that for purposes of analysis, each plan is evaluated. The process of selecting one for actual execution is not required.

The process may also be employed as an aid for *executing* a selected plan, using perhaps different criteria than those used for the plan's selection process. For both applications, information and intelligence may be used to select or reject a plan. In the first instance, it can be used to "look ahead" at break points in the OPLAN, while during a simulated conflict, it is used to decide whether or not to modify the plan, to continue to execute it, or to switch to another plan during execution of the operation.

Deciding Whether to Execute a Plan. The processes (illustrated in Figure 4.5) involved in evaluating how a chosen plan might be executed are based, in part, on the process of estimating the enemy situation.

Plan Execution

During plan execution, information and intelligence-gathering systems are mainly focused on target development, target acquisition, and battle damage assessment,

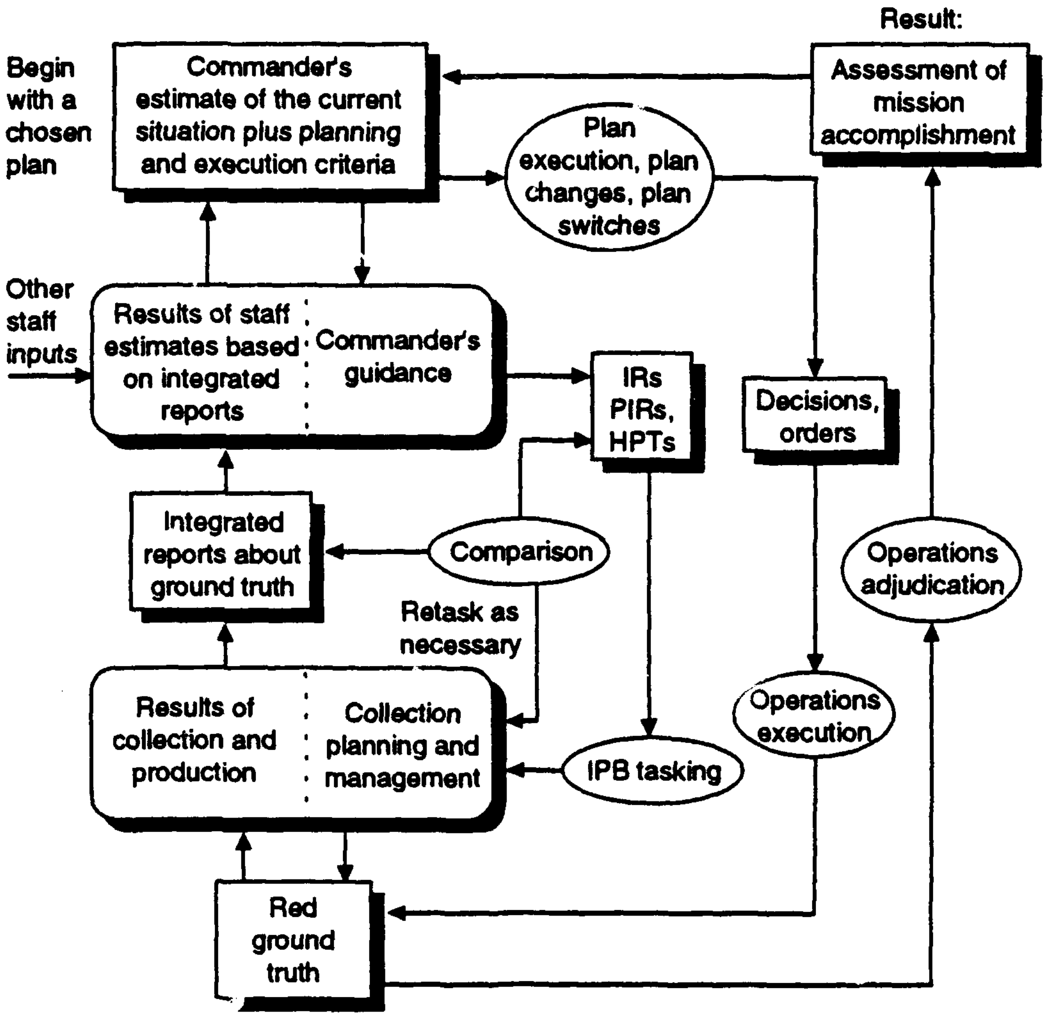

Figure 4.5—Executing a Chosen Plan: Relating Intelligence to Planning and Decisionmaking for Plan Evaluation

and much less on indications and warning and situation development. The former three intelligence functions tend to be dominated by brief time spans and spatial relationships among identifiable groupings of specific types of enemy assets, e.g., armor, mechanized infantry, air defense, artillery, and combat aviation units. Such questions as "Where are specific types of units located and what are they doing?" "Are they moving? Where? How fast?" "On which radio nets are they communicating?" and various possible combinations are typical of those that need to be reported on for plan assessments during conflict execution. By comparing maps of the same areas with results of simulated collection of two or more different and complementary collection systems, the analyst can develop essential information about the enemy's capabilities and intentions for decisionmaking and plan execution.

During campaign execution, and depending upon the unfolding situation and other dynamics, the plan may have to be modified or switched. For this reason, it *is* necessary to integrate information and intelligence to determine their relevance to executing a plan and to periodically reevaluate the situation by "looking ahead" (especially at branch points) and predicting its likely success or failure. Integrating intelligence from various sources is intended to provide successive comprehensive estimates of the conflict situation and the area environment. This is required to gain a sufficient amount of information about enemy ground truth and, thus, to enable the commander to modify his initial or prior estimate, to update it, and to make it more accurate.

For conflict operations, there is more than one level of detail where intelligence could be integrated. For example, one might choose the most disaggregated level, concentrating on individual combat vehicles and threat signatures. Most of the time this high level of resolution is neither necessary nor desirable for this model's purpose.

The next higher level of aggregation would be groups of vehicles performing various standard combat activities as a group. Some examples are artillery batteries or air defense artillery sites. The next level of aggregation would be one or more combat units, and specified activities in standard (according to doctrine) combat formations, e.g., tank columns moving toward or away from the FEBA or area of operations.

Depending on the plan's command level of interest and the enemy force size, intelligence-collection efforts might focus on battalion, brigade, division, or corps. By describing the largest integrated threat entity types and their activities of interest to the command level executing a plan, the intelligence associated with those threat entities can be integrated ahead of time. Thus, there would be no requirement for the model to simulate the collection of intelligence data at the emitter signals level or to integrate large amounts of these types of similar and dissimilar data (e.g., individual emitter signals, trucks, armored personnel carriers (APCs), tanks, and guns) using the bottom-up approach.

Obviously, the integrated intelligence approach requires prior research to accurately describe and enter in the model's tables the important characteristics of all the various threat entities that would be expected to be part of Red ground truth. Other models, e.g., the Army's Intelligence Functional Area Model, that feature the bottom-up approach may provide some of the integrated intelligence data the OPVIEW model can use. The studies that were used to provide input data for the high-resolution models should also assist. The capabilities of the various IEW/TA systems to gather individual signatures of aggregated threat entities and report the presence,

size, identity, and location of threat entity collectives, i.e., units, are contained in the databases of high-resolution models or the studies that support them. We believe that most of this research to furnish these kinds of data has already been done and the data are available from Army studies to enter in the model's tables.

Plan Breaking During Execution. For deciding whether a plan will break during operations execution, thresholds can be set by the analyst which, if breached, would prevent the plan from being carried out. An example of this might be the enemy's first use of NBC weapons if the plan was based on an initial assumption that they would not be used. See Figure 4.3 and associated text.

Plan Enabling During Execution. Integrated information and intelligence from a variety of sources *are* required to shape and to continually reshape the commander's estimate of the situation so he can decide if conditions continue to be suitable for accomplishing his mission as prescribed in the plan. This is accomplished by the model using an iterative process that compares event- and time-driven estimates of ground truth with collection results. This process is described in the discussion of the model's intelligence submodel operations.

Highlights of the Decision Submodel

These are the key features of the decision submodel:

- Accurate and flexible representations of named areas of interest (NAIs), TAIs, and PIRs;
- Use of phaselines, e.g., for a counterattack plan;
- Overall plan structure with user-defined aspects;
- Modularized missions; and
- Ability of intelligence system coverage to respond to PIRs, TAIs, and NAIs (current or new).

Additional information on the decision submodel is presented in Appendix B.

INTELLIGENCE SUBMODEL

This section describes the intelligence submodel and its place within the dynamic model's system. In particular, it explains how intelligence results in the model's simulations can have a direct bearing on the commander's (i.e., the decision submodel's) performance, and, conversely, how the commander can influence the effectiveness of intelligence collection. The potential effects on conflict outcome should be obvious. By choosing a particular course of action based upon imperfect information, forces may be either misdirected or less well coordinated or synchronized, surprised or deceived, detected, attacked, or apprehended, and so on. Thus, the model's objective of showing the effect of intelligence on conflict outcome is satisfied.

We refer to the dynamic submodel's perspective as "top-down," with the starting point for the intelligence submodel being the commander's information needs. Figure 4.6 illustrates the direction of the data flow within the submodel. We will refer to it in the following discussion.

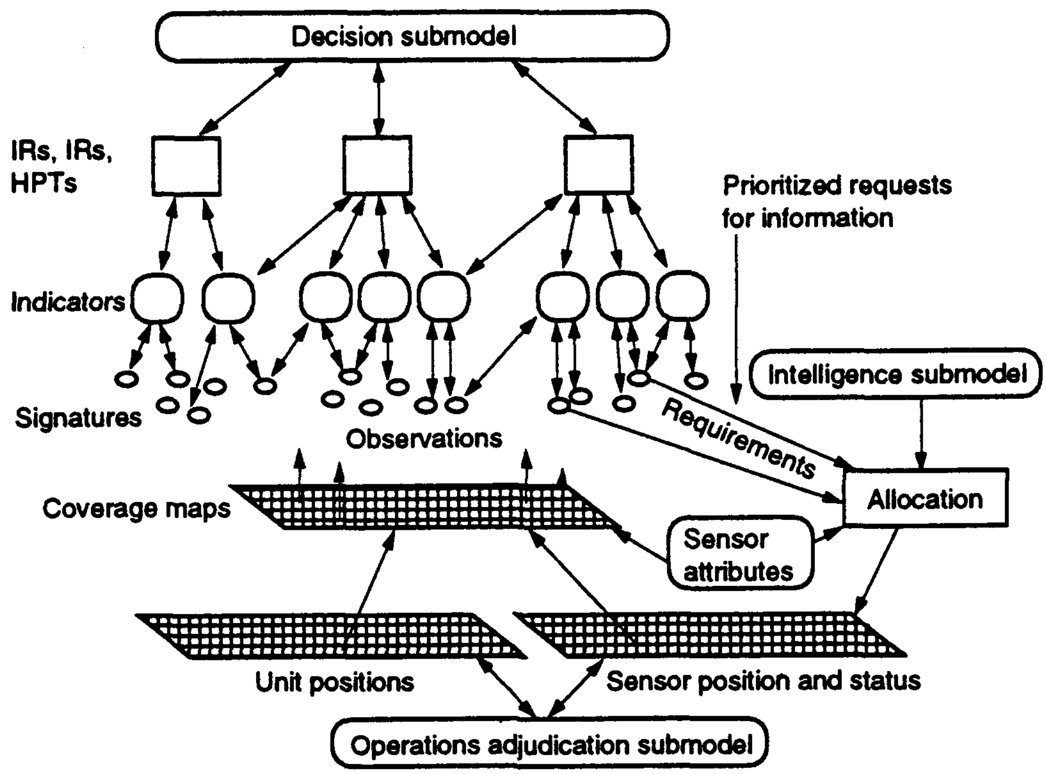

Figure 4.6—The Dynamic Model's Intelligence Data Flow

Critical Information Requirements

Certain key pieces of information are determined by a commander to be important to the conduct of an operation: PIRs and HPTs, as well as other IRs. In the dynamic model, the decision submodel uses RAND-ABEL decision tables that request various pieces of information, such as "I want to know when an enemy unit goes through area X" or "Where is the armored division of this corps?" These PIRs are defined by the user as a function of the scenario and the plan being implemented. The PIRs must first be defined by the user, but once defined, the model uses that information to allocate sensors and compare intelligence data to the current plan.

The non-intelligence battlefield operating systems are considered in the development of the concept of operation and scheme of maneuver. We highlighted the intelligence systems, since that is what is being analyzed. The other battlefield systems are considered when determining the starting values for the intelligence systems, e.g., targeting, tracking, and accuracy. These other battlefield operating systems form the basis for the PIR and HPT information for the decision sub-model, as depicted in Figure 4.6. Since this is a two-sided methodology, the information must be generated for Red and Blue.

It is important to realize that a set of information requirements is associated with each segment of a plan within the decision submodel. By causing a new segment to be selected, a piece of information can cause the decision submodel to change its subsequent information requirements. This is, then, an important feedback loop

formed between these two submodels. But perhaps an even more important feedback loop is the one that exists between information requirements and the allocation of intelligence assets. This is perhaps where the top-down approach has its biggest payoff, as we shall see.

Coverage

At the bottom of Figure 4.6, the intelligence submodel represents coverage. By this we mean that the various sensor and processing systems provide the capability to "see" certain entities (e.g., enemy units and activities) in certain places (e.g., to the rear, on the flanks, or in rough terrain) at particular levels of accuracy and timeliness—this overall capability is what we refer to as coverage. Because of this orientation, the first action performed upon the commander's (i.e., the decision submodel's) request for information is an examination of whether sufficient coverage—of the right type and in the right place—exists to extract that information. If coverage is lacking, available assets can be tasked to fill the gap, if they are not already committed, or can be preempted from a lower-priority task. More information on this is provided below.

Sensor Submodel: Generating Coverage

The conceptual abstractions of indicators and signatures must eventually be linked with a model of physical phenomena; this is the sensor submodel. In brief, it examines all the sensors in the modeled area, determining their status, operating altitude, and so on, and combines this information with knowledge of external factors, such as weather, terrain, and countermeasures. The result is a set of coverage *maps*. These maps can be thought of as overlays on top of the operations adjudication submodel's simulated conflict area (e.g., battlefield); they indicate how well that area can be "seen" by various modes of observation, according to selected "INTs" and how these assets are employed. For example, one map will represent the ability to see movement of ground vehicles, while another might represent the ability to detect artillery fire.

Allocation

In our description so far we have traversed the intelligence submodel from the commander's needs to the actual intelligence assets within or above the conflict area. The positioning and operating modes of these assets have a direct bearing on how well the signatures of threat entities can be detected. Thus, in the dynamic model, allocation is based on the particular signatures being looked for. This fairly simple process involves examining the list of the commander's information requirements from highest priority to lowest, and assigning (and possibly even preempting) other available assets to fill any gaps in the required coverage. In terms of implementation within the intelligence submodel, the allocation process occurs simultaneously with the request for information; however, this does not exclude the modeling of delays in deployment, transmission, or processing. It simply means that the need for alloca-

tion is recognized at the time the request for information is made and the model's software prompts the analyst to provide it (see Figure 4.7).[6]

The Intelligence Integration Process

The process used to integrate collection results from the same and from disparate types, mixes, and quantities of sensor systems is described in more detail in Appendix C.

Briefly, there is not a sophisticated intelligence fusion process in the current version of the OPVIEW dynamic model, although one might be added. Given two assets (type 1 and type 2), the combined coverage is given by the equation: combined coverage = $1 - (1 - C_1)(1 - C_2)$, where C_i is the coverage of the i_{th} asset. For example, if C_1 is 0.6, and C_2 is 0.25, the combined coverage is 0.7. One could implement a more detailed fusion process in the model, such as the fusion algorithms in the IEW/FAM model. In the meantime, additional coverage does not provide contradictory information, but does provide a better picture. In effect, the additional coverage provides only part of the remaining picture still not seen.

Example: Effects of Darkness on CCPFs and Total Time Scores

Figure 4.8 presents a sample of the types of effects accounted for in the intelligence submodel. In this case, we represented the effects of darkness on the ability of different types of sensors to perform their various coverage missions, as well as delays in the timeliness of the information. The effect as implemented in this model is to apply a single multiplier to the CCPFs of a given sensor. Note that a different multiplier for darkness may be applied to each type of sensor.

Highlights of Intelligence Submodel

These are the highlights of the intelligence submodel's features.

- Flexible design for defining and redefining sensor parameters;
- Efficient coverage calculations (effective range from platform to center of each cell on the terrain grid map);
- Comparable inputs with the static model;
- Efficient design for units tracked by type of sensor and category;
- Useful for tracking Blue and Red units by Blue sensors (and by Red sensors as well);
- Accounting for timeliness of data (two ways) and CCPF modifying factors; and
- Perceived versus actual database and displays (Blue and Red).

[6]In our own experience, the analyst usually prefers to designate the allocation and employment of these assets explicity and does not tend to rely on the automated sensor allocation scheme.

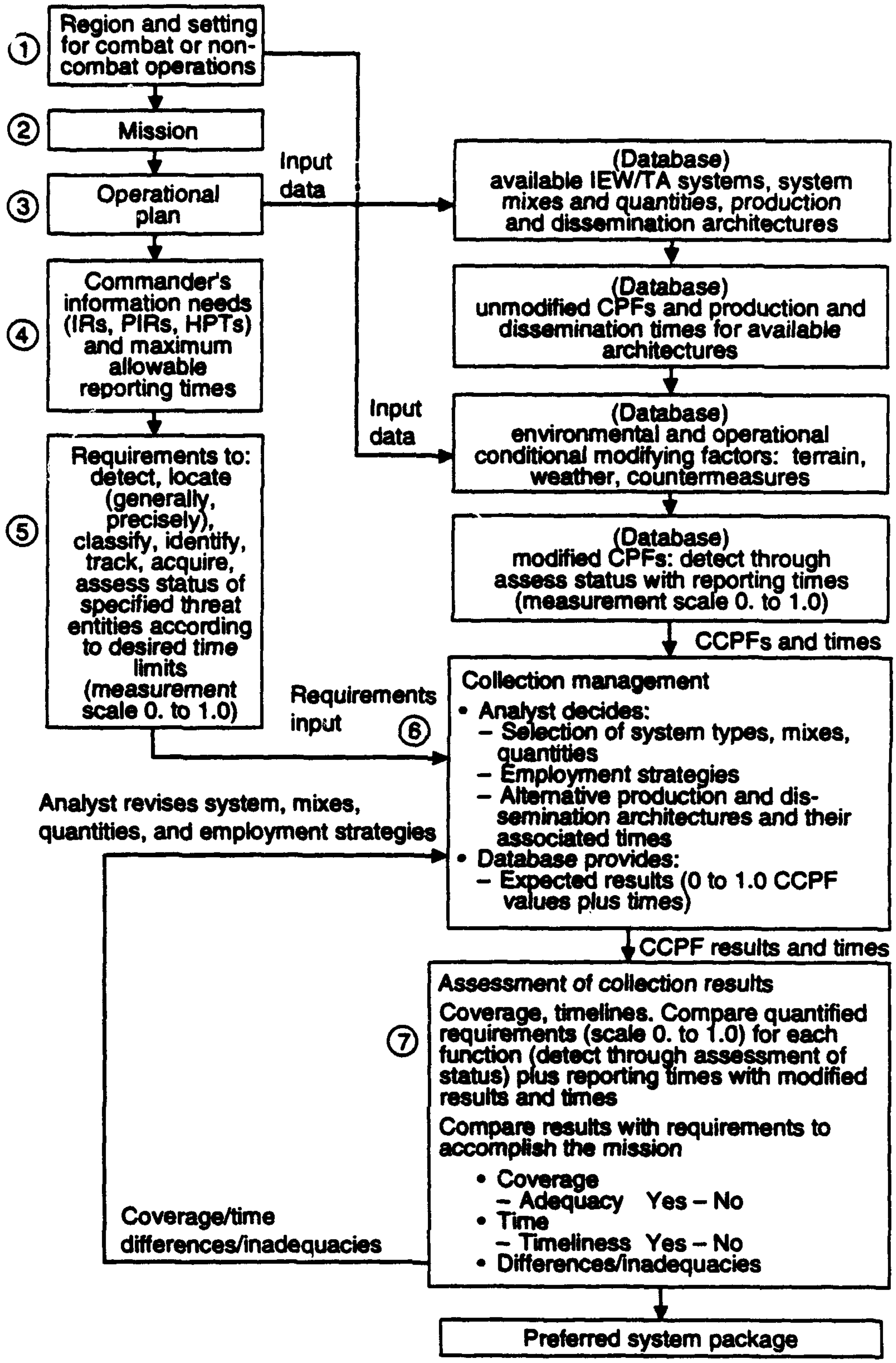

Figure 4.7—Steps in the Dynamic Model's Collection System Results Integration Process to Derive Preferred IEW/TA System Packages

Collection Systems	Percentage Modification of Conditional Collection Probability Factors: Detect	Locate Generally	Locate Precisely	Classify	Identify	Track	Assess Operational Status	Information Timeliness
Other IMINT[1,2]	0%	→	→	→	→	→	→	
Senior Warrior								
Senior Ruby								
Senior Spear								
ASARS								
JSTARS								
UAV-CR[1,2]	50%	→	→	→	→	→	→	
UAV-SR[1,2]	50%	→	→	→	→	→	→	
UAV-E								
EP3 Orion								
GRCS								
AQF[3]	75%	→	→	→	→	→	→	
GBCS (L)								
GBCS (H)								
Rivet Joint								
PRD-12[3]	75%	→	→	→	→	→	→	
Trackwolf								
Other COMINT								
Other ELINT								
HUMINT[1,3]	75%	→	→	→	→	→	→	75%
HUMINT Controlled[1,3]	75%	→	→	→	→	→	→	75%
IPW								
CI[3]	75%	→	→	→	→	→	→	75%
DOC EX								
TECHINT								
Other MASINT								

NOTE: Blank entry indicates darkness is not expected to affect collection (sensor or platform), intelligence production, or dissemination of results.

1. Imagery in the visible range.
2. Affects equally all the functions of the system; however, values are expected to be highly situation dependent.
3. Darkness may limit collection platform mobility.

Figure 4.8—Modifications of CCPFs and Information Timeliness Because of Darkness

OPERATIONS ADJUDICATION SUBMODEL

Overview

The operations adjudication submodel can be used to calculate conflict outcomes of a particular set of Blue and Red planning decisions as modified by ground truth. For example, Blue may formulate a plan with the expectation that the conflict outcome in terms of FLOT movement would be more favorable if Blue remained in a prepared defense posture for two more days rather than moving to a deliberate defense posture. When conflict is ultimately adjudicated in the model, the Blue commander may not have been able to continue defending in his prepared defense position because Red surprised Blue with a flank attack; thus, the actual combat outcome would be different from that anticipated by the Blue plan. This formulation provides for examination of simulated combat over a wide range of conditions and allows the analyst to make inferences concerning the relationships among IEW/TA's effects on decisions and to intervene to bring about changes in the conflict's results.

The list below gives the principal inputs and outputs of the operations adjudication submodel. Appendix D provides a more detailed description of it.

Input and source:
- Force orders from the decision model
- Sensor survivability from the intelligence model
- Tactical intelligence from the intelligence model

Output and destination:
- Ground truth to the intelligence model
- Battle outcomes to the intelligence model for enemy focus
- Battle outcomes to the decision model for friendly forces

The operations adjudication submodel referees the actual operation. Functionally, it "owns" and manages ground truth, and attrits and assesses damage to forces, targets, and sensors.

Although the model operates essentially at the corps and EAC levels, the operations adjudication submodel makes use of a list of brigades and regiments (with combat power measured in equipment divisions (EDs)) and their locations. Subunits of brigades (maneuver forces, motorized rifle regiments, mechanized rifle regiments, etc.) are handled parametrically. Attrition of forces will depend on the type of force, type of conflict, force ratio, and intelligence preparation.

Although initial design and modeling work has been done, the operations adjudication model is in an early developmental stage. Many of the conceptual issues have become clear. For example, the attributes of "cells" (the building-block for the game board), and how various types of units (e.g., MRL (multiple rocket launcher)) should be maneuvered within cells, etc., require revision and further development.

The intelligence systems that would produce combat information about the enemy would be normally categorized as HUMINT, although the introduction of technology such as unmanned aerial vehicles introduces a new perspective to the definition of combat information. The value of OPVIEW is that it can stimulate discussion of traditional ways of viewing the battlefield, such as: How is combat information defined

in the real world and in simulations? If the traditional definition is intended, then this really has tactical value as opposed to operational value for combat adjudication. If it is timely and has operational value, then it is reflected implicitly in the orders to friendly forces. In simulations, this is aggregated into the appraisal of expected combat outcomes through whatever combat weapons system assessment is being used. For example, the current OPVIEW methodology uses a weapons systems score aggregated to a force score, usually of brigade or division strength. Some Army models use a target-shooter differential equation to generate system kills; however, in the end, orders to forces, even in current Army models, are usually the result of some force score component, of directly implementing a planned action at a particular time or in reaction to a particular event. OPVIEW does not distinguish combat information in high-resolution detail, since it is usually not germane to operational decisions and outcomes.

Measuring Results of Noncombat Operations

The project also conceptualized (but did not implement) a way to measure operational outcomes and integrate them across various scenarios based upon the results of collection operations in noncombat scenarios. For this we considered modifying the model's adjudicator for combat operations. Theoretically, the adjudicator for a peacekeeping operation could be used to evaluate results in terms of how well (e.g., how much distance and for how long) combat-capable opponents in the region are kept separated from each other or within their own borders for the duration of an operation or campaign. Several other indicators for measuring the success of peacemaking and peacekeeping operations might be used, for example, an increase or decrease in the number of serious incidents over a specified period of time.

Other kinds of noncombat operations could pertain to rescue operations. Results could be measured in casualty avoidance, lives saved, the number of individuals relocated to safer areas, or other similar quantifiable measures of desired or undesired states.

Operations Adjudication Submodel Inputs

Force order inputs essentially consist of movement orders (e.g., wait, go to a path, go off a path), missions (e.g., attack, defend), and targeting (e.g., fire on cell x). Missions may be specified for an entire avenue of approach, or for particular units that are in cells off existing avenues of approach.

Sensor survivability inputs consist of information either provided by the default tables already in the model's database or entered by the analyst, specifying attrition rates for sensors and packages under various circumstances, which should be differentiated between the sensor platforms and threat situation.

Intelligence inputs consist of sensor and intelligence information that directly effects operations outcomes, such as the availability of counterfire radar or knowledge of enemy tactical disposition.

Operations Adjudication Submodel Outputs

Detailed specifications of outputs from operations adjudication have been developed. These specifications result from detailed knowledge of the information needs of the decision and intelligence submodels.

Ground truth consists of the actual position and status of each Red and Blue unit. Information on the terrain for each cell on or off avenues of approach is included in ground truth. Weather is available as a modifier either across the whole region of operations at the same time, or according to sections (e.g., groups of cells) at different times, and it can dramatically increase or degrade the performance estimates of intelligence assets under varying operational and environmental conditions. Treatment of nonunit targets, such as bridges, has not yet been discussed in detail. The intelligence submodel can receive from operations adjudication basic ground truth information on forces (in EDs), paths, location, and activity, as well as control of avenues or groups of cells.

Conflict outcomes consist of order of battle, position, and status information as of the last cycle of adjudication. This includes type of conflict for all units and cell-by-cell accounting of conflict outcome statistics, such as attrition force ratio, or FLOT movement. Additional work needs to be done to refine the types of conflicts (particularly noncombat), their outcomes, and the effects of intelligence on these conflicts.

Highlights of the Operations Adjudication Submodel

- Units may be moved along paths, or off paths, anywhere on the grid for free two-dimensional movement.
- Paths are flexible and can be changed even while the model is running.
- Units can be ordered to move to the nearest path, and thereby automatically move across intervening paths.
- Sensor platform fractional attrition provides for deterministic representation and is included.
- A stochastic (random) option for platform attrition is included.
- Movement over multiple cells in a single time period is allowed.
- Diagonal movement and operations can take place.
- Various types of conflicts (e.g., flank attacks) can be modeled.
- Simplified airborne/air assault and amphibious movements can be represented.
- Day/night distinctions are made.
- Weather effects on visibility (across an entire region at once or in separate, smaller areas, according to time of day, if desired) can be modeled.

DYNAMIC MODEL OUTPUTS

Since the dynamic model has not yet been used to support a large or detailed study, we cannot present sample outputs of a "realistic" situation. However, Figure 4.9

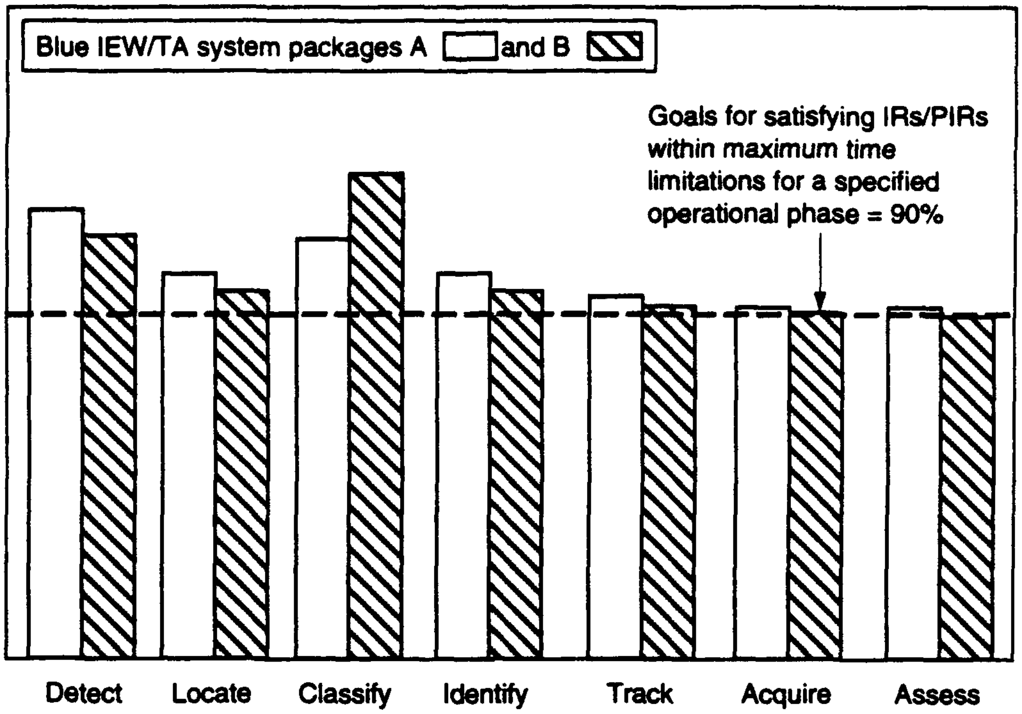

Figure 4.9—Ability to Meet Collection Goals by Two Types of IEW/TA System Packages with Different System Mixes

displays hypothetical results of an analysis of two IEW/TA system packages, employed for a specific operational phase, with a choice of different mixes (system types and quantities). Although both packages can meet the minimum criteria for collection coverage and for timeliness (including production and dissemination), Package A is the more capable.

The analyst might use this information to compare the operational "costs" of each package, and, in this illustration, he might decide to choose Package B if the number of IEW/TA assets required to be tasked would be fewer or if there were other operational reasons. The analyst might also want to compare illustrations of other similar results to see which packages meet or fall below the criteria he sets to determine the effects of changing the mix of systems and their quantities in several packages.

A second illustrative display, of the percentage of Red and Blue attrition, appears in Figure 4.10.

DYNAMIC MODEL STATUS

Two-Sidedness

The model is designed to be two-sided, and the code and data structure exist for both sides. However, there are currently very few data in the model on Red intelligence sensors, their capabilities, their doctrine for employment, and their effectiveness. Additional work will be required to make this a truly two-sided model that can provide realistic data for threat assets for a range of possible Reds.

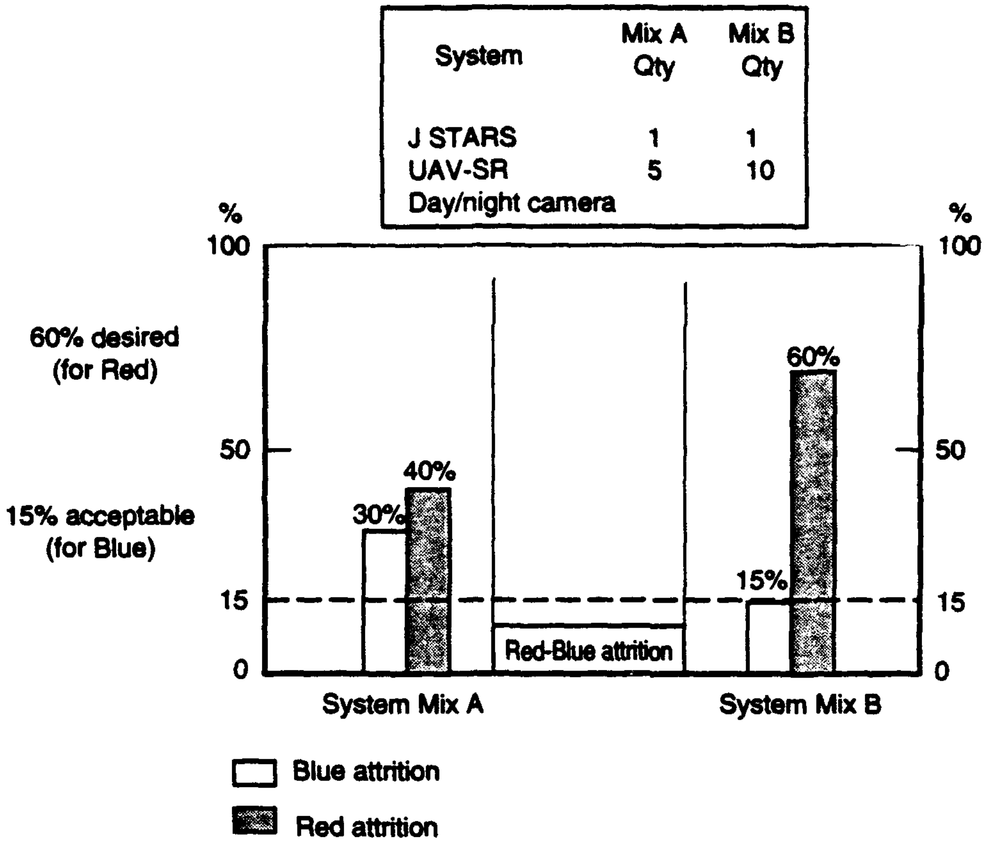

Figure 4.10—Sample Results from the Dynamic Model

Scenarios and Operations Vignettes

The model's current tables on forces pertain to NATO, U.S., Soviet, and Iraqi units and equipment and focus on the U.S. VII Corps sector in Central Europe and Southwest Asia. The current version in the model of NATO's U.S. VII Corps sector was used as a prototype to aid early model development work. A scenario has been written for conflict in Southwest Asia and was gamed in preparation for coding and entering more data and rule sets in the model and subsequently by performing sensitivity analysis.

Highlights of the Dynamic Model

- Permits detailed sensitivity analysis of selected issues;
- Provides insights about issues involving area coverage over time, system employment strategies, effecting variations in operations, and environmental and operational constraints;
- Enables synergism of complementary systems to be measured;

- Can be used to evaluate plans and plan changes; and
- Can help track relationships between collection-system choices and their results, and effects on decisionmaking and operational outcomes.

Limitations of the Dynamic Tool

- Requires significant setup time to prepare operations vignettes and enter them in the model (e.g., 2-1/2 man-days were required to completely write and enter in the model a corps-size operation for Southwest Asia);
- Requires comprehensive databases on forces and equipment; and
- Requires operator competence in the RAND-ABEL language and computer skills to run the model.

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

The OPVIEW project advanced the state of the art of intelligence measurement and valuation. Before development of the methodology and the prototype models, the Army had no credible, reliable, or systematic method for performing analysis to derive quantifiable measures of value for answering such questions as these:

- What is the contribution of IEW/TA's capability to operational utility?
- How does intelligence specifically relate to decisionmaking, plan choices, and plan changes?
- When (under what circumstances) does intelligence have value?
- Why does it have value?
  - What combinations (types, quantities, mixes) are valuable?
  - Which collection systems contribute to the performance of others, e.g., cueing, warning?
  - Which collection systems contribute to indications and warning, situation development, target development, target acquisition, and postattack residual operations capability assessment?
  - Which collection systems contribute to indications and warning, situation development, weapons employment, and assessing operational results, i.e., battle damage assessment?
  - What is the actual availability, and utility, during a given period of time and for a specific sector, of various collection systems to support deep fires, e.g., when limited to standoff collection means?
  - Which collection systems contribute to maneuver?

Answers to these questions await comprehensive sensitivity analysis of a large number of cases; however, the methodology and models for performing the analysis are now available.

The Army, in conjunction with the other Services, may want to use the methodology and models to construct and maintain comprehensive databases (for Blue and various Red forces), similar to the data contained in *JMEM* for munitions effects, only

instead, on the effectiveness of IEW/TA systems when employed either independently or in various combinations.

The Army has used the OPVIEW methodology in several studies. In addition to being used in analytic support of the MI Relook Task Force (see Chapter Three), the methodology was used to make recommendations for new IEW/TA system programs. That study applied the OPVIEW methodology to help the DCSINT support decisions for the 1992–1997 POM, particularly as related to eight new IEW systems the Army referred to as the IEW pacing systems. The study made specific recommendations concerning system types and quantities required at corps and division. The recommendations are contained in Cesar et al. (1990).

Although both the dynamic model and the static model prototypes have been completed and their feasibility has been demonstrated in the two studies mentioned above, additional development work is required to evolve and tailor model variations to suit the needs of several user groups. Additional and updated data will be required for these versions. The new data needed include:

- Comprehensive and verified CPFs and CCPFs for all current and developmental Blue IEW/TA systems, including those of the other Services and the national systems.[1]
- Comparable data for the various possible Red forces.
- Timeliness data for the connectivity architectures of both Blue and possible Red collection, processing, production, and dissemination systems.
- Further development of the operations adjudication submodel for noncombat operations and entering supporting data in the model's tables.

RECOMMENDATIONS

The principal users of models for performing value-added analysis, e.g., operations planners, resource providers and allocators, and asset allocators, will have distinctly different, yet potentially highly complementary, perspectives. Each group will have its own objectives and criteria for measuring added value. Even so, the OPVIEW methodology and its models can be used by all these groups by adapting them with software, rule sets, and supporting data tailored to the needs of each user group. A number of the tables and data can be used by all groups in common.

Consequently, we recommend that the Army designate a single manager to be responsible for the further development of the models and their upgrades, and for acquiring and verifying data for their tables. A related recommendation is for the Army's manager to achieve and maintain interoperability between OPVIEW and other current and developing management processes and models, e.g., FIM at the U.S. Army Intelligence Agency and the AIMP at the U.S. Army Intelligence Center.

We also recommend that the Army endorse a policy and develop new procedures for verifying and validating behavioral type models such as OPVIEW (see Appendix G for a discussion), and that the next iteration of the AIMP include specific assignments

[1]CPFs and CCPFs should be defined based on quantifiable systems studies and operational experiences, rather than relying solely on expert judgment.

and tasks and a plan, with milestones, for actually performing verification and validation of the applications versions of the OPVIEW models.

The list below presents some criteria for measuring value added to operations planners:

- Coverage
  - Resolution
  - Depth
  - Width
  - Revisit periodicity
- Product reports information:
  - Adequacy
  - Accuracy
  - Timeliness
- System
  - Mobility
  - Supportability
  - Operational flexibility
  - Synchronization with the operational plan
  - Support for the operational continuum
  - Protection of the force

The following list includes criteria for measuring value added to resource providers and *allocators:*

- Provides solution sets
  - Meets warfighter operational requirements
  - Supports both combat and noncombat operations
- Provides balance, worldwide, across:
  - Service programs, peacetime contingencies
  - Army programs
  - Force structure, by type of command
- Other Army Programs:
  - Force readiness
  - Training
  - Doctrine development, support
  - Needed technical capabilities, according to intelligence discipline
  - Production
- Provides focus balanced across all of the above areas
- Flexibility
  - Ability to shift resources to and within programs
  - Be prepared for other contingencies and unplanned situations
- Force projection, deployability
- Synchronization
  - Joint
  - Services
  - Combined operations

- Provides adequate operational continuum

The next list shows criteria for measuring value added to asset apportioners:

- Balance according to
  - Command echelon
  - Mix
  - Quantity in the region
  - Intelligence discipline
  - Protection of the force
- Focus
  - Operational center, e.g., weight the attack
  - Protection against operational uncertainty
    - Rear
    - Flanks
- Flexibility, ability to rapidly reapportion assets within the region to meet new operational demands
- Synchronization
  - Operational plans in the region
  - With the other Services and agencies represented
  - With coalition forces
- Supportability
  - Logistics
  - Operator personnel

Although the OPVIEW methodology and models were developed at the request of and for adoption by the Army, we hope that they will be considered by other Services and agencies as well, with the goal of providing a common framework throughout the Department of Defense and the analysis community for conducting analysis related to measuring the value of intelligence capabilities.

We believe that the methods and processes developed in this study can be adapted to other areas besides intelligence. They are intended as tools to help analysts decide such issues as which policies to promulgate, which applied research programs to approve, which technologies to promote, and which changes should be made to Joint and Army doctrine, system employment strategies, and training programs, along with many other factors, all of which can contribute to improved policy analysis and decisions.

We also believe there is a need for a new joint publication, which might be called the *Joint Information Effectiveness Manual (JIEM)* and be similar to the *Joint Munitions Effectiveness Manual (JMEM)* except that it would provide credible data on IEW/TA system effectiveness, instead of munitions effectiveness, to the analytic community and other users. Although the JTENS Handbook and the DIA manual on intelligence systems give the technical characteristics of the various friendly intelligence systems, they do not provide data about what the systems will collect under various environmental conditions or operational settings (e.g., various platform operating altitudes). What we believe would be very useful for analysts are the kinds of (expert certified) data needed about both friendly and enemy systems in table form for use with the OPVIEW models and any other similar models. Intelligence and conflict-related re-

sults would be derived for both the collection and production means and would be evaluated under a variety of combat and noncombat situations and other environmental conditions. We recommend that the need for such a manual be analyzed.

Appendix A
OPVIEW'S MEASURES

DEFINITION OF TERMS

The research issue for this project centered on the ability to relate IEW/TA performance and effectiveness through a credible and repeatable process to arrive at variations in operational results. The operational value of IEW/TA systems is obtained by analyzing a variety of measures comprising both quantitative and qualitative factors. This study has categorized these measures in the following terms: Measure of Performance (MOP), Measure of Effectiveness (MOE), Measure of Utility (MOU), Measure of Results (MOR), and Measure of Value (MOV), defined below. See Table A.1.

MEASURES OF PERFORMANCE

Measures of performance relate to system-level phenomena and are obtained from system specification publications, e.g., Mission Essential Needs Statements (MENS) and operational Requirement Documents (ORD), system technical descriptions, and technical manuals.

MEASURES OF EFFECTIVENESS

Measures of effectiveness are revised MOP characteristics for a given system when it is deployed, since system effectiveness is then usually less than the full capabilities of the system design. Political and operational constraints, effects of weather and terrain, and enemy countermeasures, *inter alia*, all serve to limit the potential performance of any system. They are measured in relation to the constraints that describe the reduced potential performance of each system. MOEs are also measured in relation to the command-level decisions required to plan and accomplish the unit's mission. Thus, they are the integrating link between purely physical phenomena, situation-dependent factors, and command decisionmaking.

MEASURES OF UTILITY

Measures of utility refer to the capability of one IEW/TA system or a mix in a given operational setting to support a decision within the chosen time period for analysis. Utility is measured by the collected information's timeliness, accuracy, adequacy, and understandability, plus tradeoffs among these measures.

Table A.1

OPVIEW's Measures

Measures of Performance (MOPs)	Measures of Effectiveness (MOEs)	Measures of Utility (MOUs)	Measures of Results (MORs)	Measures of Value (MOVs)
Parametric characteristics of IEW/TA system designed performance, e.g.: Platform Speed Altitude Endurance Vulnerability	Modified IEW/TA system performance according to the operational setting, employment doctrine, and strategy constraints, plus the effects of: Weather Topography Countermeasures	Measured utility of one IEW/TA system, or a mix, in a given operational setting, to support a decision within the chosen time step for analysis	Measured combat results of a campaign, battle, engagement, or decision branch point of a particular plan that is affected by IEW/TA system performance	Summarized value contributions of a given IEW/TA system, or mix, to mission accomplishment
Sensor Area coverage Electromagnetic spectrum Sensitivity Resolution Signal-to-noise ratio Jammer Area coverage Electromagnetic spectrum Effective radiated power	*Effectiveness* is measured by comparing operational capabilities with designed performance	*Utility* is measured by the collected information's: Timeliness Adequacy Accuracy Understandability (plus tradeoffs)	*Results* are measured in terms of mission accomplishment derived from conflict outcomes, e.g.: Attrition FLOT movement Force ratio change Control of the initiative Hostile force separation	*Value* is measured in terms of mission accomplishment over a range of: Different theaters Various operational phases Mission Command level Red and Blue forces Employment doctrines

MEASURES OF RESULTS

The Army must plan for a variety of contingency missions, and uncertainty can exist within each mission concerning how combat or noncombat operations would actually occur. Thus, military planners must prepare contingency plans and make force development decisions under some particular set of assumptions. Problems in analysis and frustration in planning arise because there is usually an extreme sensitivity to multiple assumptions. Measures of results produced by a single simulation run are prone to high uncertainties because of inadequate sensitivity analysis.

By evaluating the expected performance of each IEW/TA system, both individually and in combination with others, an analytic relationship can be established between the commander's information needs and intelligence requirements (IRs, PIRs, HPTs) for executing his mission. Comparisons are made between the requirements for information to support the mission and results obtained from the collection-planning and collection-execution steps. Tradeoffs are then made between the products of IEW/TA:

- Timeliness;
- Relevance to mission and command level;
- Accuracy;
- Adequacy; and
- Comprehensiveness (plausibility, understandability, language interpretation/ translation, decryption).

Subsequently, comparisons are made again, this time between the operational requirements and results achieved to arrive at MORs.

We have defined measures of (operational) results to be the increased opportunity for each side to accomplish its mission in more favorable or less unfavorable situations, where favorable is defined as desirable measured operational outcomes:

For Combat Operations

- Control of the initiative, e.g., attack, defend;
- Attrition inflicted on each side;
- Change in control of territory, i.e., FLOT movement;
- Relative posture of each side after a battle, i.e., change in force ratio; and
- The ability to avoid being surprised, or deceived, and to inflict surprise or deception.

For Noncombat Operations

- The ability to maintain the lowest possible level of conflict, e.g., the increase or decrease in the number of riots or other serious events, over some period of time;
- The ability to keep opposing factions separated, e.g., by the distance of their longest-range weapons;

- The ability to promptly extract U.S. dependents or other civilians from a hostile environment without casualties;
- The ability to provide specific types and quantities of aid to relieve human suffering, e.g., food, water, shelter, medical supplies, security, and other types of care; and
- The ability to evacuate military or civilian personnel from existing or impending danger.

MEASURES OF VALUE

Measures of value are the summarized values attributed to IEW/TA, or other systems, that are derived from sufficient and often extensive sensitivity analyses of the measures of results.

In the most aggregated form, value can be judged by making a change in IEW/TA capabilities to one or both sides and then counting the increase or decrease in the number and mix of potential, simulated combat or noncombat situations that are determined to be favorable to one side or the other.

The OPVIEW process is structured so that many cases can be examined in a short period of time, thus enabling a credible and highly relevant range of sensitivity analyses to be performed. Sensitivity analysis enables analysts to address questions concerning IEW/TA value, such as:

- What is the contribution of IEW/TA capability to combat (or noncombat) utility?
- When (under what circumstances) does it have value?
- Why does it have value?
- What combinations (mixes of IEW/TA systems) are valuable?
- Which sensors contribute to helping other sensors meet the intelligence requirements in a specific situation?
- Which sensors contribute to supporting weapons?
- Which sensors contribute to force employment strategies?
- Which sensors contribute to interdiction and maneuver?
- Which production capabilities or arrangements contribute to timely generation and dissemination of intelligence and other information reports?

The military planner, having examined a large number of cases, can arrive at conclusions concerning which mix of IEW/TA systems and force structure dominates other mixes in the context of Army missions. Resource implications can then be considered to arrive at program decisions in a manner consistent with mission accomplishment. This process leads to a forum in which Army planners can discuss the value of the total IEW/TA force rather than focusing on marginal changes in the lowest-priority items.

DECISION SUBMODEL

This appendix supplements the discussion of the decision submodel presented in Chapter Four and contains some of its more technical features. The decision submodel is one of several components of the dynamic model that interacts with the combat adjudication, sensor, and intelligence submodels. These components operate off common representations of ground truth, including force structure, sensor assets, coverage laydowns, and terrain. They share interfaces that allow them to send orders, report events, and establish intelligence requirements.

The decision submodel provides the commander's perspective in modeling the concept of operations of each of two opposing sides, one the friendly or Blue side, the other the enemy or Red side. Each side has associated with it a set of decision processes whose hierarchical relationship reflects the command hierarchy of the side being modeled. Each decision process is the model's embodiment of the commander of that level in a military command structure, for example, a corps commander. Each such process has a corresponding operations plan that it executes.

The plans are written in the RAND-ABEL programming language, which was developed at RAND to provide a syntax readable by analysts with only modest computer background. The language also includes table statements that are easily modified by the analyst without having to change the overall structure of the plan. The sleep and wake mechanisms used in coprocesses are part of the run-time support that RAND-ABEL provides for simulation.[1]

Operations plans contain the mission statement, force requirements, phaselines, prioritized intelligence requirements, and high-priority targets in its definition. In addition, the plan uses situation-development and target-development routines to develop a picture of the conflict area and potential plan options. These routines use ground truth in assessing the forces of its own side and intelligence reports to assess the forces of the enemy. The final portion of the plan has preparation and execution phases and moves, and within them deployment, strike, and other orders to particular units under command.

DESIGN RATIONALE

The principle behind the design of the decision submodel is to allow the analyst to express his concept of operations from the commander's perspective in a form that is

[1]Decision submodel source files can be found in the Src/Decision directory under the top-level OPVIEW directory, e.g., /spy/o/ramp4 at RAND. That directory also includes the data dictionary files in the Dict subdirectory, and the "makefiles" found in the Make subdirectory.

easily read and modified. As a result, the model does not usurp the analyst's control over planning decisions by automatically ordering forces around. Instead, it employs a semi-automated process where the analyst works within the structure of an on-line control plan to write out the various options he wants executed. This is one of the model's important dynamic features. The plan also provides a single, central place from which all command decisions originate and are laid out roughly in chronological order for conceptual simplicity. Through interpretation of collected intelligence, the analyst can modify the current plan as needed during the course of a scenario while it is running.

The "plans use" function asks the submodel to implement basic code and structure for setting up the mission, requirements and limits for establishing intelligence priorities, etc. The analyst is free to look up any given function but can basically work in a declarative fashion in developing a plan. That is, the analyst can merely specify what should happen, deferring to the function exactly how it gets done. When desired, the function can be altered to refine the behavior of the model, but the analyst does not have to do this to get the model running initially.

REPRESENTATION OF MODEL ENTITIES

Ground Truth: Units and Force Structure

Ground truth about friendly and enemy forces is kept in the form of a list of units called the troop list. This list contains the unit's identification, its name (e.g., 1/1 Mech), original and current equivalent division score (ED is the unit of force strength used in the dynamic model), parent unit if any, its current location and destination (cell), the direction it is facing (N, E, S, W), its activity, and mission. Moreover, each unit has a breakdown by asset type giving the ED score for each type, e.g., mechanized infantry (mech), artillery (arty), armor (tanks), and ADA.

The set of organic intelligence assets is also maintained along with each unit in a separate list. Further, in the sensor submodel, a list of sensors and platforms carries extensive characteristics about the performance, reliability, responsiveness, and properties of each sensor and its "INT" type. Each platform is an independent unit that moves according to the type of platform (aerial, fixed wing, helicopter, UAV, tracked ground vehicle, and so on) and each platform carries one or more sensors. As a result, platforms can be attrited like any other unit in the simulation.

In the dynamic model, intelligence collection against enemy units is modeled, although in the current prototype, the communications network that ties together command and control is not, although we see this as a potentially valuable addition for many studies. As a result, each collection system knows ground truth about its own forces, and information regarding enemy forces is filtered through the intelligence process.

Geography: Terrain, Mobility Corridors

The area over which the model plays is a two-dimensional array of cells, 10 × 10 km, in the prototype model. By convention, the cells are addressed by row and column with the origin in the upper-left-hand corner. The row and column names of any cell can be converted to latitude and longitude of a given map. Ground units move within a cell or between adjacent cells but at any given time are always located in only one cell. Partial movement across a cell is tracked to ensure that entry into the

next cell occurs at the right time. For aerial platform assets, their ability to pass over multiple cells during a time step of the simulation is captured in the model. Also, each asset can be targeted while over any given area as well, so it can be attrited realistically.

Various attributes including terrain, mobility corridors, and the like are associated with the region's geography by a set of overlays that map onto the basic array of cells. Terrain values are enumerated as sand, wadi, rough, and so on, to indicate whether the terrain is open, mixed, or closed (rough or mountainous). The values are then employed to regulate the speed of units moving over that terrain and are also used in the attrition calculations. Units may move on or off road (if roads are present) depending on their posture. Mobility corridors, or paths as they are referred to in the model, are laid out by marking the collection of cells with the name of the path they define. These paths are laid out by the analyst as a shorthand way to refer to the principal avenues of approach each plan will employ. Movement of the threat entities off the paths is also possible, so that their movement is not limited to these paths.

Named and Target Areas of Interest

Given terrain, ground truth, and assumptions about enemy intent, the commander identifies areas that are of particular importance in carrying out his plan. For situation development, these are the NAIs, and for target development, TAIs. The NAIs and TAIs are locations that should receive priority for coverage, since they are usually associated with a commander's prioritized intelligence requirements. The NAIs currently are specified as either a specific 10 × 10 km cell or as a path containing the set of cells under it. TAIs are likewise specified, though they will generally be much more specific than NAIs, as individual units are usually being targeted.

Prioritized Intelligence Requirements

PIRs form the principal interface between the decision and intelligence submodels. PIRs are used first to establish priorities that drive the collection-management process, specifically the allocation of intelligence assets. The PIRs also provide the commander with information that can be used to determine which options to select and when to execute them in a plan.

The analyst can fill out a set of PIR tables initially to specify the priorities in the beginning of a simulation run. The PIRs can be changed subsequently when the analyst wishes. This is another important dynamic feature of the model. These tables access functions that actually pass the information to the intelligence submodel. Implicit in the functions is a specification of a NAI for each PIR, that is, the cell or path on which collection should occur. Each row in a PIR table corresponds to an individual PIR. The PIR can specify a minimum strength of a certain force type to locate (e.g., .05 EDs of Mech) or a specific unit to identify or locate (in a cell or on a path, i.e., in a NAI). In addition, the PIR can specify an activity to look for, such as tactical movement, direct or indirect fire, and so on. Finally, the required timeliness of the information used to satisfy a PIR can be specified in hours or decimal equivalent thereof.

High-Priority Targets

As with PIRs, HPTs have the dual role of conveying the commander's assessment about which enemy forces are important to deter, delay, or destroy as part of his

plan, while also conveying to the intelligence submodel which forces to collect against for target development. The structure of HPT tables is very similar to that for PIRs. Priority is conveyed by the rank order of each HPT. As in the case with PIRs, HPTs can also be changed or reordered whenever the analyst wishes. The location in this case constitutes a TAI rather than a NAI but is otherwise specified in the same terms of cell or path. With the level of resolution currently modeled in the dynamic model, it is not possible to be more precise than to identify that a unit is within a 10 × 10 km cell; it is not possible to specify where the unit is inside the cell. This could be changed, however, by defining quadrants or other subdivisions; however, for analysis at the operational level at corps and Echelons Above Corps (EAC), 10 × 10 km cells seem to be the most appropriate size. The analyst can also state a time, in hours or decimal equivalent, by which the target should be acquired to execute a strike order in a timely fashion.

Presumed Enemy Options and Intent

To capture the commander's assumptions about the enemy plan and options, the analyst can establish decision points in a table at which the enemy may exercise an option. This information is used to derive a notion of enemy intent that can be used by the friendly commander to decide the time and place to issue orders and select his own options.

The enemy commander may or may not elect to implement such options or may choose a different time to initiate them, depending on the course of the simulation. Since the enemy plan is entirely independent of the friendly plan's presumed enemy options, the enemy may in fact not even consider those options at all. Nevertheless, when the activity or other indicator associated with an enemy option is detected, that option is flagged as having been selected. The time at which it occurs is compared with the time it was expected to occur to indicate whether the option was executed earlier, on time, or later than expected.

As with PIRs, the presumed enemy options table specifies the NAI or location in terms of a cell. Each row of the table yields a particular decision point at which an enemy unit is expected to engage in some activity or mission. The time is specified as day and hour in simulation time. After a decision point has been reached and detected, the time is converted to the time of occurrence, replacing the expected value supplied by the analyst. This lets the Blue commander track the apparent progress of the enemy on his predicted course of action.

PLAN CONTENT AND STRUCTURE

Decision submodel plans are each implemented as RAND-ABEL functions. As such, these plans can be compiled or interpreted as desired. Moreover, RAND-ABEL support for simulation allows the embedding of "sleeps" in a plan to suspend execution until the next decision cycle. Execution will resume when one of the following wakeup conditions occurs: the number of hours until the next decision cycle has elapsed, a prioritized intelligence requirement has been satisfied, or a plan limit has been exceeded.

There are three basic sections to a decision submodel plan, namely, plan definition, limits and execution segments, and moves. Each section makes use of functions in the plan library to implement the programming details. The analyst can then focus

on describing what he wants the plan to do without being concerned about how it actually gets done in the model.

Plan Mission Requirements Section

The definition portion of the plan lays out the mission, objective, timing, and requirements that define the concept of operations from each commander's perspective. At the corps level, the basic mission is either defend or attack, whereas individual units (division or below) can be given more specific missions such as delay or supporting attack. Plan requirements are specified in terms of a required quantity of a particular force type, for example, 650 tanks or 0.9 reserve EDs, or in terms of a minimum force ratio. If any of these requirements is not met, a warning is issued and recorded in the log file. Ground objectives are specified in terms of phaselines and the timing associated with reaching each of them in turn. One ultimate objective can be the ground-gaining goal along one or more mobility corridors. A phaseline is coordinated across avenues of advance by identifying the row and column of the cell where the phaseline crosses each defined path. See Figure B.1 for an illustration of ground objectives and phaselines.

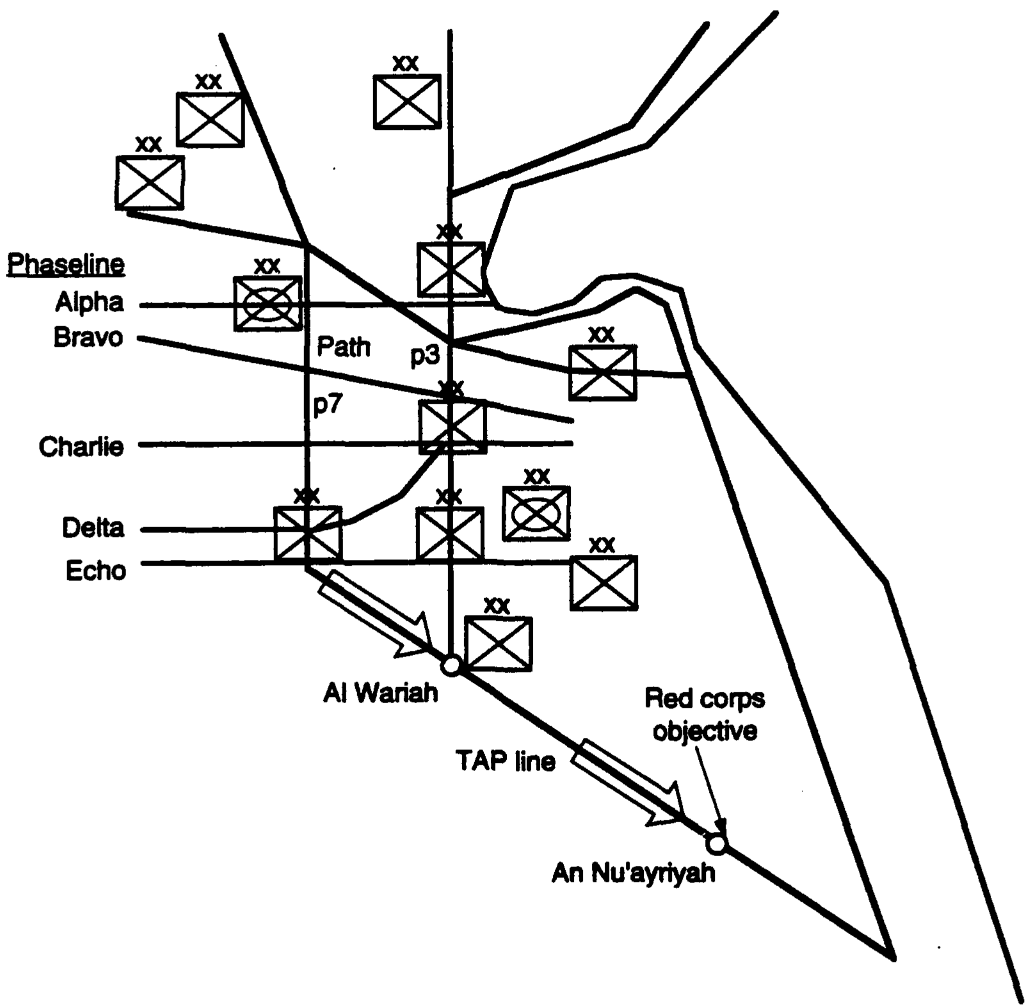

Figure B.1—Red Plan Objectives: Forces, Phaselines, and Ground Goals

The analyst can also lay out the presumed options of the enemy in terms of decision points. When these decision points are reached, the enemy presumably has executed the option associated with it, giving the analyst some insight about enemy intent.

To set the intelligence process into motion, general initial prioritized intelligence requirements can be specified to help determine allocation of intelligence assets at the outset of a run. Typically, these rough requirements specify simply the presence of a generic force type of interest and strength along an avenue of approach.

Because the definition section is executed each time the plan resumes, the parameters of the plan can be modified on the fly during a run whenever the plan is interpreted. This adds flexibility in that it is not necessary to switch out of a plan simply to make minor refinements.

Plan Limits Section

Plan limits are the set of conditions that determine when a plan is no longer appropriate for the current conflict situation. When any limit is exceeded, a warning is issued to both the control panel and the log telling the analyst that the game has stopped and is awaiting further direction from the analyst. At that point, the analyst can intervene to change plans or plan parameters before continuing the game.

Plan limits can also be set for the completion time by which a phaseline or ground goal must be reached, the force, attrition and exchange rates, and the FLOT position, and velocity. The FLOT is approximated by the location of the forwardmost units of a side along each avenue of approach. The FLOT rate then is simply the maximum rate of the forward most units.

Plan Segments Section

Plan segments implement the phases and moves of the commander's operations plan. The orders associated with the preparation and execution phases of a plan are issued in these segments, for example, deploy and strike orders. Each segment has conditional logic to determine when it will be executed. When each segment is executed, a new branch is followed along the decision tree that the analyst associates with the plan. Segments can be executed serially over time or within a move, depending on the conditions placed on each segment. A few control parameters govern which plan segments are executed at what times, namely, plan-segment and time-limit (in hours). To suspend the plan until the next decision cycle (put it to sleep), the analyst issues an exit command at the end of the plan segment.

It is also possible to switch out of a plan from any plan segment and to start a new plan in any segment. Of course, the plan writer must ensure that the plan is sufficiently prepared if it is to begin at a segment that is different from the first.

PLAN EXECUTION, BRANCHING, AND PLAN SWITCHING

Starting, Suspending, and Continuing a Plan

When a simulation run begins, a coprocess is created and a plan started for each commander to be modeled. In the dynamic model, there is one corps-level commander modeled for each side; however, there is no limit to the number of com-

manders that could be modeled or to the depth of command structure, other than available memory. The execution of these plans is intermingled with that of the combat assessment/adjudication and sensor/intelligence submodels.

The time step of the simulation is driven by the frequency with which the adjudicator updates the state of forces and intelligence assets. In other words, it would not make sense to have the plan wake every hour if the operations adjudication takes place every four hours. In practice, adjudication usually takes place every hour because of the high responsiveness of intelligence assets, although it would be possible to lengthen the time steps to adjudicate collection results, for example, in benign operational regions.

The plan usually determines whether it is time for another move, executes a segment, then exits the plan function to allow it to sleep until its next decision cycle. The next wakeup will occur at the planned time for the next move or earlier if an important event occurs. For example, the RAND-ABEL statement "Let Time-limit of 7th-Corps be Time-in-hours + 1" would set the next planned wakeup for one hour from the current game time. In addition, a function can be used to determine the conditions under which the next wakeup should occur. The statement "Let Current-plan-wakeup of 7th-Corps be the function Report-on-PIRs" would resume the plan when an intelligence report satisfied a PIR. In addition, the limit-test can be assigned a function that likewise returns "yes" or "no" to indicate whether or not the plan should wake.

At some point, there are no further options in the current plan to consider. When this occurs, the analyst can set the time limit to the special keyword "never" and use a wakeup function "Never-wake" to let the plan sleep for the remainder of the game. Nevertheless, the analyst can always stop the game to switch plans manually if desired.

Decision Cycles: Immediate and Deliberate

Because wakeup conditions can be either time- or event-driven, the plans can implement both the immediate, or event-driven, decision cycle and the deliberate, usually time-driven, planning cycle. The deliberate cycle is usually 24 hours or so and represents the time at which planned activities are initiated. On the other hand, the immediate decision cycle models the response to enemy activities or intelligence reports that require immediate action on the part of the friendly commander.

Plan Limits, Opportunities, and Thresholds

Two kinds of milestones can be associated with a plan, namely, limits and opportunities. When a limit is reached, the plan is suddenly considered outside the range of situations it was designed to handle. At that point, if a backup plan is available, that side will begin to follow the backup plan. Otherwise, the game is suspended and the analyst notified so that he can intervene to modify the plan or switch to another one. Limits can be placed on the completion time of the plan (in hours), the force ratio (Red EDs/Blue EDs), the attrition rate of friendly forces, and the exchange rate. In addition, there are limits for enemy penetration along each mobility corridor. Figure B.2 illustrates the various plan limits.

Opportunities can be identified at which a plan option can be executed or at which the commander can switch from, for example, a mobile defense plan to a counterattack plan. As with limits, opportunity criteria are specified in terms of (early) plan

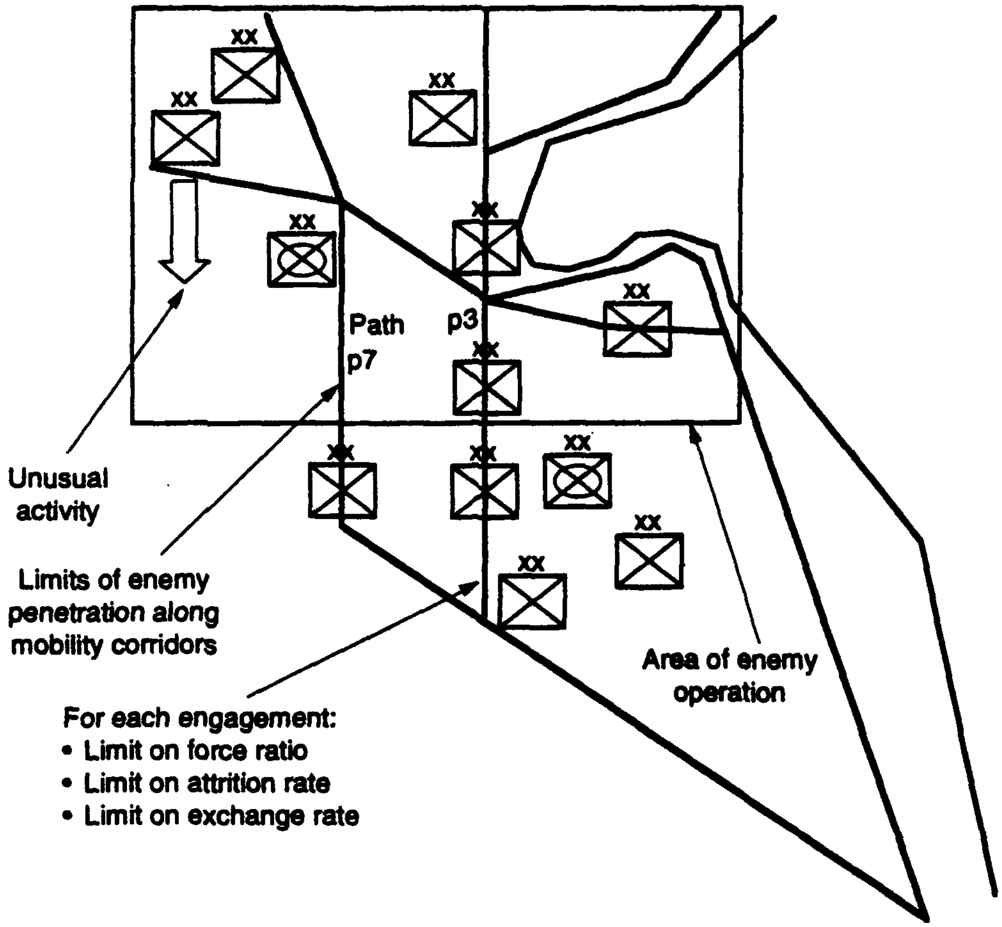

Figure B.2—Diagram Illustrating Limits on Blue Plans

completion time, a favorable force ratio, the attrition rate of enemy or friendly forces, and the exchange rate. If desired, the model could be set up to stop the game and notify the analyst of an opportunity, or an impending catastrophe, just as it does when a limit is reached. The analyst could then intervene to switch or modify plans.

Branching Versus Plan Switching

The choice of how to arrange the moves and phases of an operations plan is quite flexible. All moves, options, and contingencies can be contained in a single plan. In that case, different options would reside in different plan segments, each of which is triggered when some condition (coded in If-Then-Else logic) is true. When a particular option is implemented, a branch in the plan has been taken. At this point, the plan can switch to another plan segment when it continues execution. The RAND-ABEL statement "Let Plan-segment of 7th-Corps be 2" would change the notion of current segment in the plan.

Alternatively, different phases and options could reside in entirely separate plans. One example is that a delay option might be part of a fallback defense plan, while a flanking move might be contained within a counterattack plan. In this case, to get from one set of moves and options to another set involves switching out of the current plan and into another. To do so, the plan function is simply reassigned with a

new function name. For example, "Let Plan-function of VI-Corps be Corps 1-counterattack-plan" is the RAND-ABEL statement that does this. Figure B.3 depicts handling contingencies and switching plans.

The choice of when to use branching within a plan and when to use plan switching is actually one of convenience and aesthetics. Some options do not logically fit together in the same context; others are contingencies of the same basic plan.

Interpreting Plans

For the greatest flexibility in developing and testing plans, the analyst can interpret the plan so that modifications to the plan can be made in the middle of the simulation. The only way to do this with compiled code is to parameterize every aspect of the plan or stop the game, recompile, and then start over again. Therefore, we chose not to use compiled code. Good judgment is required to decide what is worth interpreting, since interpreted code takes up much more memory than compiled code and interpreted code is executed at least an order of magnitude slower.

To interpret a plan, or for that matter any function, the analyst copies the RAND-ABEL function from a source file to a new file located in the Run/INT directory.[2] As with all RAND-ABEL executable source files, the new file should have a .A extension so the RAND-ABEL Interpreter will know to parse it. In addition, the analyst should

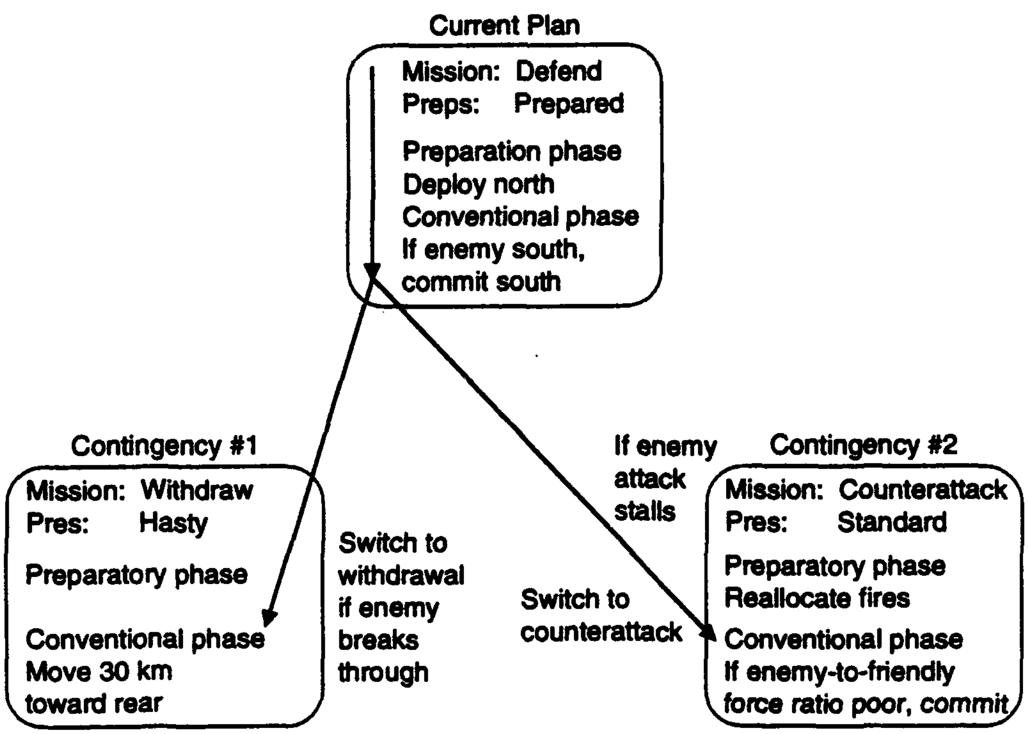

Figure B.3—Switching to a Contingency Plan

[2]Elsewhere in this report the unofficial term "INT" is used for one or more generic intelligence disciplines. It is used in this section as the title of the "interpret" part of the system's directory of the OPVIEW model.

add an owner statement at the top of the interpreted file, if one is not already there. Moreover, if there is an Include statement at the top it should be removed, especially if it refers to the data dictionary. Once placed in the INT directory, the function will be interpreted the next time the game begins or resumes execution after being stopped. The interpreter automatically recognizes when a new or modified file exists in the INT directory and parses it accordingly. Finally, should the user not wish to interpret a function, the file containing it can be moved out of the "INT" directory (for example, to one like INT/Hide). Then the next time the game resumes, the function will no longer be interpreted and the compiled image will be used instead.

DECISION PROCESS

Operations plans use three basic classes of decision process to build pictures of the conflict area, namely, situation development, target development, and the various assessment functions that evaluate the plans' progress. Of these, the situation development and assessment classes are well developed, but target development routines are still limited to the specification of high-priority targets.

Situation Development

Situation development evaluates the degree of threat as well as enemy intent and options based on intelligence reports submitted to satisfy the commander's PIRs. For example, unusual activity on the part of enemy units is assessed by looking for enemy units outside of the expected area of enemy operations (like on the flanks or in the rear) and by noticing important changes in activity that might indicate a change in mission and therefore intent. This can be applied to nonlinear operations as well to depict concurrent, dissimilar kinds of operations or conflict intensities occurring in the same region that are physically separated by substantial distances. Also, the presumed enemy options laid out as decision points by the analyst are checked during situation development to determine if a particular option has been implemented by the enemy. This constitutes the intelligence preparation of the battlefield along with the satisfaction of PIRs that focus on the areas of interest or NAIs. In other words, there is a safety net to catch enemy behavior that is outside that anticipated by the established PIRs.

Target Development

Target development is currently handled in the decision submodel by selecting high-priority targets and rank-ordering them. If we were going to model at the process levels of target acquisition and weapon engagements, the intelligence submodel would indicate when the selected targets were acquired, so that strike orders could be issued. In practice, some attrition, such as platform issues, are assessed automatically in the operations adjudication process. In other cases, the plan must decide when to strike without the feedback that the target has or has not been acquired. If desired, elaboration of this process would be a matter of further development.

As target development is characterized by a high degree of precision and timeliness of information used to guide the targeting process, the efficacy of target development could suffer if the resolution was set too low. Both the time step chosen and the cell size will affect this process. Of course, the advantage of low resolution is that the model runs fast enough to support sensitivity analysis. Nevertheless, to compensate for low resolution to some extent, important enemy weapons systems or subunits

can be carried as independent units in the model. By doing this, the analyst can track a unit independently of other units so it can be collected against individually. For example, multiple launch rocket system (MLRS) or cruise missiles could be treated in this fashion.

Plan Status and Assessment

Several functions assess the progress of the plan and track the movement of forces. The principal functions are Report-plan-status, Evaluate-requirements, and Report-enemy-movement. Report-plan-status is the highest-level assessment function that uses information from the other assessment functions to determine the status of the plan. Plan-status evaluates one of the following: Continue-plan, Refine-plan, Modify-plan, Switch-plan, or (proceed) To-next-plan. Plan-status is determined by evaluating the completion-time status, the force (ratio) status, the attrition status, and the phaseline status. Not surprisingly, these different subcategories of status break out along the same lines as the limits and opportunity criteria. The Report-plan-status function determines current values for time to plan completion, force ratio, attrition rate, and distance to next phaseline or ground goal with respect to the limit on these quantities specified in the plan.

The Evaluate plan requirements function compares the current quantity of a particular force type with the requirement specified near the top of the plan. Presumably, if not enough force exists to carry out a plan or if the ratio of friendly forces to enemy forces of that type is poor, the plan should not be implemented. At a minimum, a warning is issued to the log file so the analyst is aware that the current force strength does not meet the plan's requirements. This information could also be used as a limit on plan execution, although this constitutes more of a go/no-go decision during the preparation phase of the plan.

The function Report-enemy-movement evaluates the position and rate of advance of enemy forces along each mobility corridor identified by the analyst. The function determines whether forces are advancing, halted, or withdrawing. In the process, it identifies the lead enemy unit and associates its location and speed with the notion of the front, along with the forward limit of friendly forces.

INTERFACES WITH OTHER SUBMODELS

The principal interfaces between the decision submodel and other components of the dynamic model consist of those that communicate with the collection-management and intelligence processes and those that send orders to forces and examine ground truth.

Intelligence Submodel Interfaces: Specifying PIRs and HPTs

To relate intelligence collection to decisionmaking, an interface exists between the commander and his staff (as represented in the model) and the intelligence staff carrying out allocation, processing, and collected intelligence integration functions. The PIRs constitute the means for the commander to specify NAIs and establish priorities that will drive the allocation of intelligence assets. They also form the basis of the intelligence preparation of the battlefield and are important to determining enemy intent and selecting plan options. The high-level PIRs are broken down in the intelligence process into a collection of diagnostic and contributing indicators that are checked by comparing the coverage and capabilities of sensors with the signature

and emissions of different enemy forces. What often matters to the commander, however, is simply whether or not the enemy is mounting a main attack and if so where.

Five slightly different functions that are accessed from tables or queried individually specify PIRs, namely, Establish-Intel-unit-ID-PIR, Establish-Intel-unit-EDs-PIR, Establish-Intel-unit-EDs-in-cell-PIR, Establish-Intel-subunit-PIR, and Establish-Intel-subunits-in-cell-PIR. The first function is used to identify a specific unit; the others specify a generic type of unit or a specific subunit type, such as mechanized, infantry, tanks, artillery, and ADA. The location, or NAI, is specified as a cell or as a mobility corridor. The PIR sequence number (pir# rank-orders) sequences the PIRs, while report by hours or decimal parts thereof determines how timely the information must be to satisfy the PIR. One set returns a probability that the assertion of a particular PIR is true. Each PIR effectively asserts that a certain force involved in a certain activity or moving in some direction is present in the specified NAI (cell or path location).

High-priority target tables are the target development analog to PIRs. They are organized in a similar way and allow the probability that is returned to be associated with the ability to acquire the target specified in the TAI (again, given as a cell or path location).

Operations Adjudication Interface: Orders

The primary way the commander can implement the phases, moves, and options of his plan is by issuing orders to his forces. Accordingly, three basic order functions are invoked, namely, the Order-deploy, Order-commit, and Order-strike functions. Order-deploy causes the named unit identified by troop ID to deploy to the mobility corridor or cell. In addition, the function assigns a mission to that unit. Order-commit is similar to deploy but is used to commit reserves behind frontline echelons along a mobility corridor.

Order-strike results in an attack on a specific enemy unit or generic force type at the specified location. The order is issued to a specific friendly unit given by troop ID. Further, the type of munitions load (antitank is the default) and time-frame can be given to determine more precisely how and when the order will be carried out.

PLAN LIBRARY

The plan library consists of the basic code and structure for plan control and assessments functions. Most of the time, the analyst need not concern himself with the plan control functions. However, the assessment functions can be tailored to suit the analyst's style of interaction and to reflect more closely his values.

Wakeup and Plan Control Functions

The basic structure of the coprocesses mechanism and sleep and wakeup functions that alternately suspend and resume the plans is contained in the source files top-level.A and plan-control.A. At the top level in the function Decision-model, the side of each command is identified along with a set of wakeup functions, before the plan is invoked. Initialization is also performed here before the plan begins. The plan name, time-limit, and wakeup function name are merely parameters to allow any of these to be changed by the plan or by the analyst as needed.

The plan is invoked via the Plan-control function from an outer function, namely, Decision-model, that has the sleep and wake forever loop (until the game ends). This allows the plan itself to be interpreted at any time, because it completes its actions before the next sleep. This is necessary, since a plan cannot be interpreted if its compiled image is still active. For similar reasons, the coprocess associated with the plan must be started from the top-level function with the forever loop. Otherwise, if a coprocess were started from a subordinate function, its context would be lost when the function exited—the next time that plan was to resume, it would fail.

As mentioned above, three basic wakeup functions are tested each time-step, namely the Time-limit associated with the deliberate planning cycle and the boolean wakeup functions Current-plan-wakeup and Limit-test. The Current-plan-wakeup is usually set to Report-on-PIRs so that even if the planning cycle is longer (say 24 hours), the plan will wake as soon as an intelligence report is received that would satisfy a PIR. The Limit-test is set to Never-wake, since the game is set to stop and notify the analyst anyway. Nevertheless, that logic could be changed and the Limit-test set to Test-limit-exceeded instead, if desired.

Assessment Functions

As mentioned above, a set of assessment functions are invoked to perform the details of situation development and plan status. Some of these are generic functions shared by the two sides, whereas others are specific to a side, such as where attacker/defender asymmetries exist. Report-enemy-activity is an example of a generic function that simply checks for unusual or significant changes in unit activity (regardless of side) and reports whether the change is likely to be favorable or unfavorable to the friendly side. On the other hand, Report-enemy-movement is an example of a function that depends on side, to get the attacker or defender perspective correct for determining deepest penetration and the notion of FLOT rate along each mobility corridor.

MODEL OUTPUTS AND GRAPHICS

With all the background about the model design, the user is still missing one important part: to understand the course of events that occurred in the simulation, namely, the modes by which a running simulation can be monitored and by which game output can be postprocessed. There are three basic ways to examine a dynamic model simulation run, namely, to browse the log file, to bring up Data Editor tableaus, or to display graphics in MAPVIEW. In addition, the user can abstract the data from the log or Data Editor and load it into a spreadsheet.

Log File

Aside from various debug logs in the Run/DB directory, the log file of principal interest to the analyst is the, "agent.userid" file in the Run/O directory. For a user named Smith, the log file name would be "agent.smith0". The file contains an English-like chronological log of all events and activities in the simulation for all submodels. The decision submodel output can be identified by sections beginning with "Executing plan...in plan segment n" and surrounded by lines of "*****" above and below. The log for each plan indicates when intelligence reports satisfy a PIR, when orders are issued, when limits have been exceeded, and what the current plan status is. Some of the information is from the so-called "bird's eye view," meaning that of the analyst,

while other information is from the commander's more limited perspective reported by his means of collection. That information, which is based on enemy ground truth, such as, warnings of inadequate force ratios or changes in enemy activity, is logged with the prefix "Analyst advisory:" to emphasize that the information is for the game controller, but is otherwise unknown to either the Red or Blue commander. The operations adjudicator also writes reports to the logs that are directed toward the analyst to monitor how each engagement is proceeding. Engagement results from the operations adjudicator can be observed in either the look-ahead, plan change, or end-of-game modes.

The decision submodel makes decisions based on the perceived situation. To compare the perceived situation with the actual situation, the analyst needs to have access to both the actual model assessment and that side's perception of the situation. Table B.1 presents sample outputs from the Log file from the operations assessment submodel. In this example, platforms numbered one through 40 are Blue, and the Red units are prefaced with an "r". Letters in brackets fill in additional letters not listed in the actual Log file.

Data Editor Tableaus

Two sets of tableaus, or interactive tables, are displayed by the Data Editor, one each for Blue and Red sides. These tableau sets can be found in the files red-map.T and blue-map.T in the Run/T directory. Each file contains information giving the state of the simulation from that commander's perspective (or from that of the corresponding controller).

Figure B.4 presents a portion of a computer "screendump" that shows the platforms by name (Blue or Red), its current activity, its current location (by cell), and a list of 5 destinations. The destinations with "0" under the "hrs" column mean that that cell is a waypoint on the path to a loiter or orbit position. Any positive number under hrs is the number of hours the platform will perform its mission at that location. For example, platform p17 (UAV Close range with an IR sensor package) is currently at its first destination orbit location (row 30 column 46) and will remain there a total of 4 hours before moving to the next loiter position at cell row 39 and column 40. To continue the example, platform p18 (another UAV Close range with an IR sensor

Table B.1

Sample Log File Outputs

```
*************
Conflict adjudication at 25 hours
*************
platform p40 in Wait at 25.00 hours begins Move
platform p1 in orbit [at] 25.00 hours begins Move [to new destination]
[Unit] r1 Mech [in] rough terrain N[ot on] highway [travelling at] 5.0 kph
[Unit] r6 Mech [in] rough terrain Y[es on] highway [travelling at] 22.0 kph
[Unit] r29 Inf [in] sandy terrain N[ot on] highway [travelling at] 2.0 kph
[Unit] r1 moves 5.0 [kms] in cell R[ow]41 C[olumn]47
[Unit] r6 moves 6.7 [kms] to new cell R[ow]37 C[olumn]49
[Unit] r29 moves 0.28 [kms] to new cell R[ow]30 C[olumn]44
[Unit] r14 Main-att N[ot at] destination Y[es] in combat
[Unit] r14 [old posture] Tac-move becomes [new posture] Assault
```

Platform Deployment

	blue name	red name	acti vity	current row	col	dest-0 row	col	hrs	dest-1 row	col	hrs	dest-2 row	col	hrs	dest-3 row	col	hrs	dest-4 row	col
p1	GRCS	--	Orbi	r44	c37	r44	c37	24	--	--	0	--	--	0	--	--	0	--	--
p2	GRCS	--	Orbi	r49	c46	r49	c46	24	--	--	0	--	--	0	--	--	0	--	--
p3	GRCS	--	Orbi	r51	c54	r51	c54	24	--	--	0	--	--	0	--	--	0	--	--
p4	SENIOR	--	Wait	r80	c80	--	--	0	--	--	0	--	--	0	--	--	0	--	--
p5	SENIOR	--	Wait	r85	c78	--	--	0	--	--	0	--	--	0	--	--	0	--	--
p6	SENIOR	--	Wait	r90	c75	--	--	0	--	--	0	--	--	0	--	--	0	--	--
p7	SENIOR	--	Wait	r85	c78	--	--	0	--	--	0	--	--	0	--	--	0	--	--
p8	SENIOR	--	Wait	r80	c80	--	--	0	--	--	0	--	--	0	--	--	0	--	--
p9	ASARS	--	Orbi	r52	c41	r52	c41	24	--	--	0	--	--	0	--	--	0	--	--
p10	JSTARS	--	Orbi	r52	c45	r52	c45	24	--	--	0	--	--	0	--	--	0	--	--
p11	JSTARS	--	Wait	r90	c75	--	--	0	--	--	0	--	--	0	--	--	0	--	--
p12	UAV-C-	--	Wait	r80	c80	--	--	0	--	--	0	--	--	0	--	--	0	--	--
p13	UAV-C-	--	Wait	r82	c79	--	--	0	--	--	0	--	--	0	--	--	0	--	--
p14	UAV-C-	--	Wait	r90	c75	--	--	0	--	--	0	--	--	0	--	--	0	--	--
p15	UAV-C-	--	Wait	r47	c44	--	--	0	--	--	0	--	--	0	--	--	0	--	--
p16	UAV-C-	--	Wait	r47	c46	--	--	0	--	--	0	--	--	0	--	--	0	--	--
p17	UAV-C-	--	Orbi	r30	c46	r39	c44	0	r30	c46	4	r39	c40	0	--	--	0	--	--
p18	UAV-C-	--	Move	r34	c46	r39	c45	0	r27	c48	4	r40	c47	0	--	--	0	--	--
p19	UAV-SR	--	Wait	r90	c80	--	--	0	--	--	0	--	--	0	--	--	0	--	--
p20	UAV-SR	--	Wait	r47	c48	--	--	0	--	--	0	--	--	0	--	--	0	--	--
p21	UAV-SR	--	Orbi	r29	c42	r39	c43	0	r29	c42	4	r29	c44	4	r39	c49	0	--	--
p22	UAV-E-	--	Wait	r80	c80	--	--	0	--	--	0	--	--	0	--	--	0	--	--
p23	UAV-E-	--	Wait	r90	c75	--	--	0	--	--	0	--	--	0	--	--	0	--	--
p24	UAV-E-	--	Wait	r85	c78	--	--	0	--	--	0	--	--	0	--	--	0	--	--
p25	UAV-E-	--	Wait	r82	c79	--	--	0	--	--	0	--	--	0	--	--	0	--	--
p26	UAV-E-	--	Wait	r90	c75	--	--	0	--	--	0	--	--	0	--	--	0	--	--
p27	EP-3-O	--	Wait	r80	c80	--	--	0	--	--	0	--	--	0	--	--	0	--	--
p28	GRCS	--	Wait	r85	c78	--	--	0	--	--	0	--	--	0	--	--	0	--	--
p29	AQF	--	Wait	r90	c75	--	--	0	--	--	0	--	--	0	--	--	0	--	--
p30	RIVET-	--	Wait	r80	c80	--	--	0	--	--	0	--	--	0	--	--	0	--	--
p31	RIVET-	--	Wait	r80	c80	--	--	0	--	--	0	--	--	0	--	--	0	--	--
p32	RIVET-	--	Wait	r90	c75	--	--	0	--	--	0	--	--	0	--	--	0	--	--
p33	TAC-AI	--	Wait	r85	c78	--	--	0	--	--	0	--	--	0	--	--	0	--	--
p34	TAC-AI	--	Wait	r80	c80	--	--	0	--	--	0	--	--	0	--	--	0	--	--
p35	GUARDR	--	Wait	r80	c80	--	--	0	--	--	0	--	--	0	--	--	0	--	--
p36	QUICKF	--	Wait	r90	c75	--	--	0	--	--	0	--	--	0	--	--	0	--	--
p37	QUICKF	--	Wait	r80	c80	--	--	0	--	--	0	--	--	0	--	--	0	--	--
p38	QUICKF	--	Wait	r85	c78	--	--	0	--	--	0	--	--	0	--	--	0	--	--
p39	QUICKF	--	Wait	r90	c75	--	--	0	--	--	0	--	--	0	--	--	0	--	--
p40	APS-94	--	Wait	r85	c78	--	--	0	--	--	0	--	--	0	--	--	0	--	--
p41	APS-94	--	Wait	r80	c80	--	--	0	--	--	0	--	--	0	--	--	0	--	--
p42	USD-9X	--	Wait	r90	c75	--	--	0	--	--	0	--	--	0	--	--	0	--	--
p43	USD-9X	--	Wait	r80	c80	--	--	0	--	--	0	--	--	0	--	--	0	--	--
p44	QUICKL	--	Wait	r90	c75	--	--	0	--	--	0	--	--	0	--	--	0	--	--
p45	QUICKL	--	Wait	r80	c80	--	--	0	--	--	0	--	--	0	--	--	0	--	--

Figure B.4—Sample Data Editor Output

package) is currently moving through row 34 column 46 on its way to its first destination point at row 27 column 48.

Tableaus also give the current location and status of each unit, and the status on each avenue of approach, including the limits on deep penetration, the forward position of the enemy and its lead unit, direction of movement, and prior position. Other tableaus show situation development in terms of presumed enemy options for mission, activity, and movement at a particular time and place. Another tableau shows plan status with respect to force ratio, attrition rate, exchange rate, and plan completion time.

A separate tableau indicates progress toward the next phaseline on each avenue of advance by presenting the ultimate ground goal, the current phaseline to achieve, the time by which to reach it according to the plan, and the current location and

identity of the unit leading the advance. Requirements are monitored in three additional tableaus that show required force ratios and friendly and enemy quantities of various force types. Finally, a set of tableaus are overlays on the cell-based map giving force ratio, attrition rate, limit exceeded (or not), opportunities, sensor assets and platforms, and terrain features for each cell on the map.

MAPVIEW Displays

An easy way to visualize the events in a dynamic model simulation is to use the displays provided by MAPVIEW[3] (see Figures B.5, B.6, B.7, and B.8). To run MAPVIEW, the analyst will need a MAPVIEW file in his home directory.

The basic theater layout containing mobility corridors, coastline, and other boundaries can be loaded with the "Load Objects" menu option of MAPVIEW. This is done by selecting the file "theater.goal" from the scrollable list. To display icons giving unit locations over time, the analyst first must extract that information from the Log file using the "extract-units" script. That will produce a file "units.goal", which can be loaded into MAPVIEW. In addition, he can load an image of terrain by selecting "Load Image" and the file "terrain.ras" from the menu and scroll list.

Figures B.5 through B.8 illustrate the MAPVIEW outputs of the dynamic model.

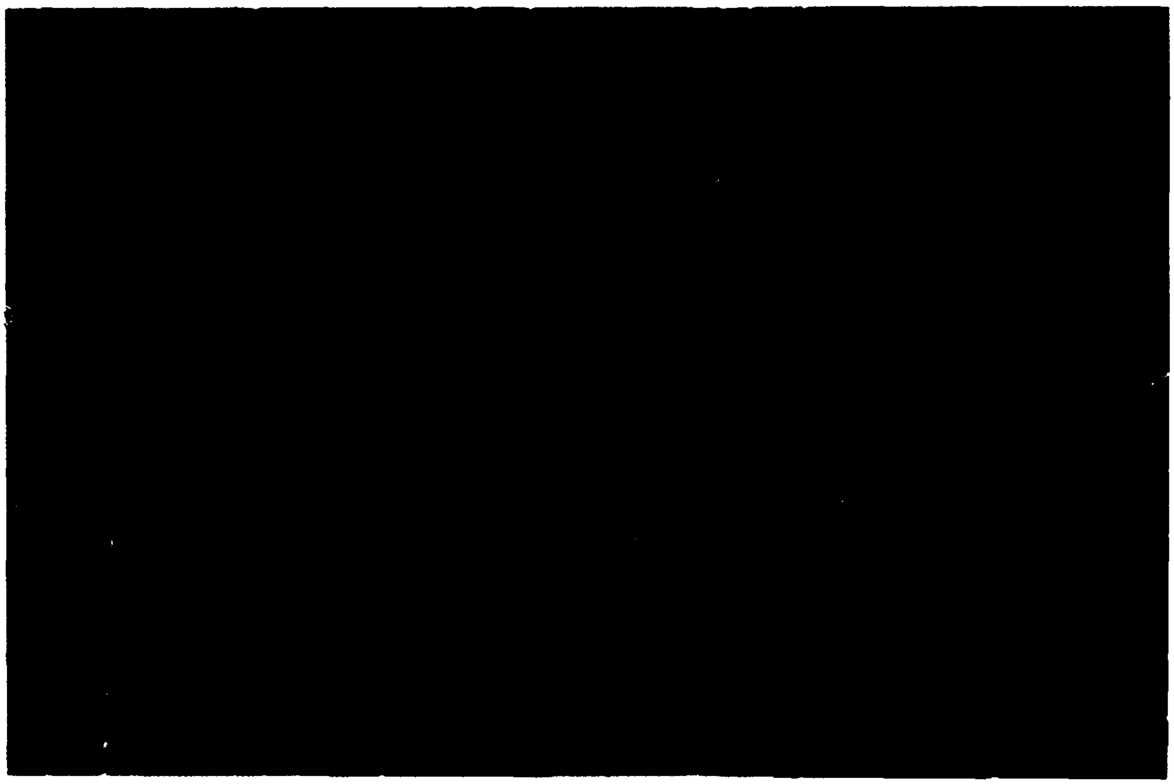

Figure B.5—Dynamic Model Terrain and Forces

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[3]MAPVIEW is a graphics tool, developed at RAND, that can be used to illustrate the movement of icons along mobility corridors and terrain cells. It is an X-based graphics tool for illustrating simulation objects overlayed on a background of terrain features or coverage laydowns.

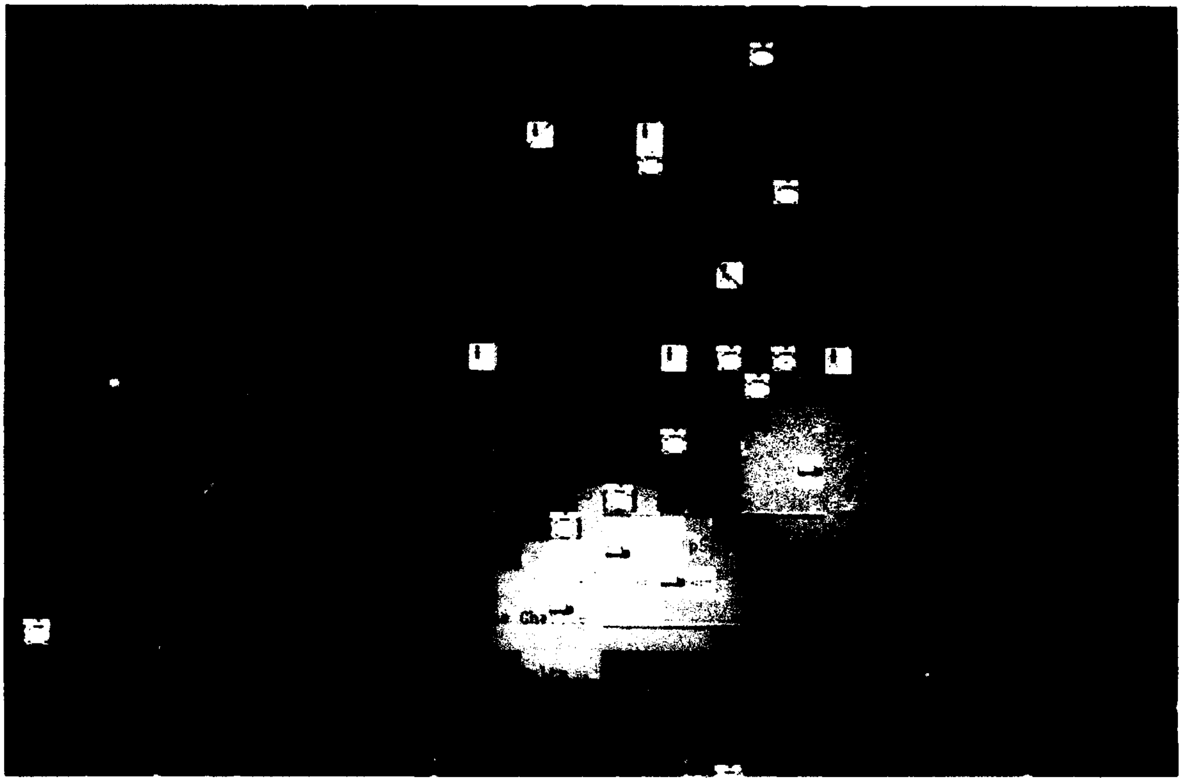

Figure B.6—Dynamic Model Coverage Map Hour 0

The scenario in Figure B.5 is the Kuwait theater of operations. The dynamic model uses a terrain grid divided into 10 × 10 km squares. Water is shown in blue, open terrain is grey, wadi is green, and sandy areas are brown. The white paths are used to help control the movement of units, but units are not restricted to maneuvering on the paths. Units can move anywhere on the two-dimensional surface, from the center of any square to the center of any other square. Units may be ordered to follow a path or to move to a square and then follow a path, or vice versa. This is important, since if units were restricted only to paths, it would be fairly easy to allocate one's sensors to focus only on the paths. Since units may move anywhere, sensors must be able to cover off-path areas as well.

Operational units in the model are currently resolved at brigade- and regiment-sized units. Types of units include infantry, mechanized, armored, armored cavalry, and artillery. This scenario begins with Iraqi forces crossing through Kuwait, having bypassed some of the Kuwaiti forces. The sensor types represented in this scenario include HUMINT, UAVs, GBCS, SIGINT, GUARDRAIL Common Sensor, ASARS, and JSTARS. The model runs at one-hour time increments and executes an hour of model time in about 5 minutes.

Figure B.6 displays the coverage map of Blue sensors at hour zero. The lighter the shade, the higher the detection coverage. A six-shade gray pallet was used, although the degree of coverage (in CCPF terms) is shown in the model on a scale of 0 to 99.

Figure B.7—Dynamic Model Coverage Map Hour 4

HUMINT assets associated with operational units and deep HUMINT teams (represented by the figure of a person) can detect fairly well only in the terrain grid they occupy. The GBCS (van symbol) can detect very well in its grid square and to a lesser degree in adjacent squares. The UAVs can detect fairly well in the grid square they occupy but move around the conflict area more quickly than HUMINT assets.

Off the lower right of the map at an airbase are a JSTARS, an ASARS, and three GRCS. Their coverage is quite extensive and will cover most of the area once these assets reach their orbit locations. In this illustration, this coverage appears as a grey patch in the lower-right-hand corner of the map. Once these assets are in their orbits, it will be more difficult to see the exact coverage of the shorter-ranged collection assets. However, the model accounts for both the area and point detection effects of different types of sensors. Although the CCPFs are calculated separately for each of the eight categories, the coverage map is currently specified only for the detection intelligence category.

At hour four, the JSTARS, ASARS, and three GRCS are in their orbits (see Figure B.7). The coverage map extends far enough to include a large number of enemy units in the "white" region, representing a high degree of coverage. There are other forces in the light grey area and in the darker grey regions. The model calculates the degree of detection of each enemy unit based upon the types of assets detecting it and the degree of coverage in each of the eight categories.

The UAVs have been launched and are flying to their loiter positions. Multiple loiter positions with different loiter times may be specified to one-hour time periods. The

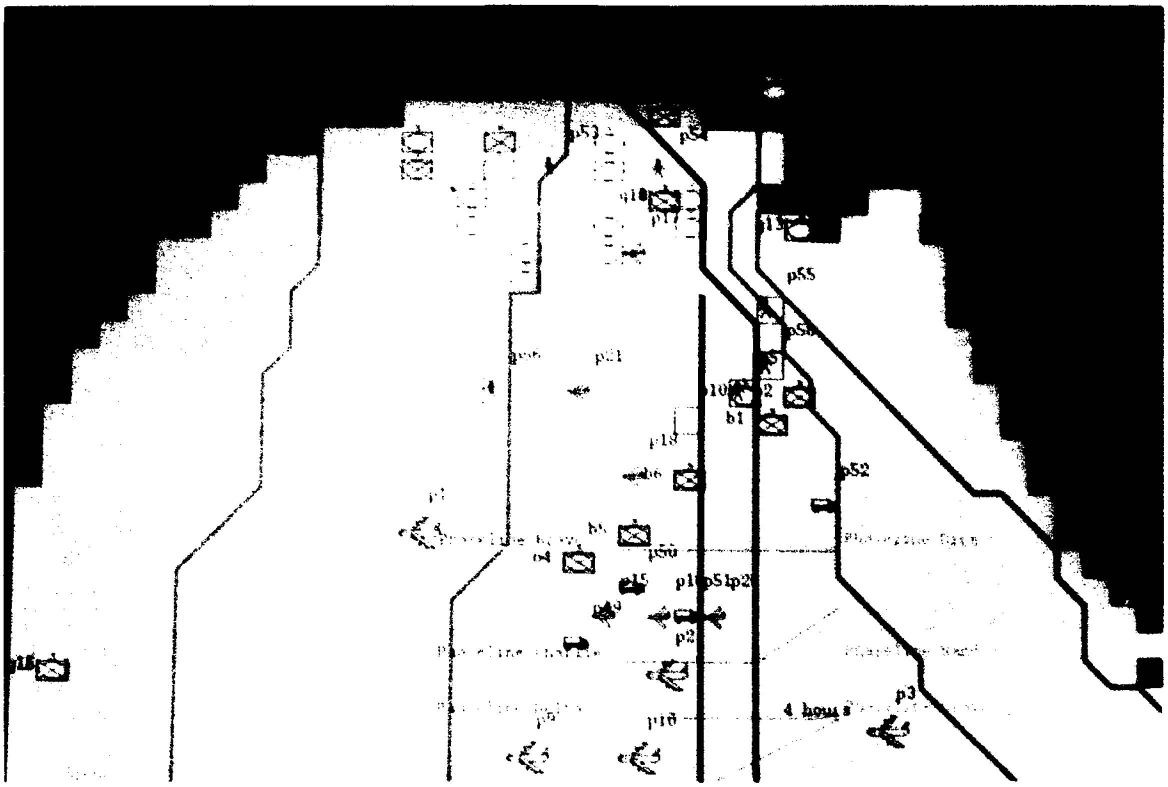

Figure B.8—Dynamic Model Blue Perception Hour 4

UAV flight paths were designed to penetrate where enemy air defenses are weak, although they will be at risk when flying over or near enemy units.

Attrition of intelligence assets in the model can be deterministic or stochastic. In the stochastic version, a sensor either survives or is killed based upon a random number generator. The higher the enemy active countermeasure threat, and the less survivable the platform, the more likely the platform will be destroyed. In the deterministic version, platforms receive a cumulative percentage damage that proportionally reduces their coverage. The deterministic version represents the average coverage that could be obtained by that sensor over many repetitions.

Figure B.8 displays the Blue perception of the conflict area at hour four. Note that the identity of the Red units has been removed to reflect the best information currently available on enemy units. For each enemy unit, the model tracks the degree of current coverage in each of the eight intelligence categories and the types of sensors providing that coverage. An enemy unit can be undetected, whereupon no symbol is shown. If the enemy unit is detected, then only an empty icon is shown. If the unit's size can be determined, then the size symbol is included on the icon. If the type of unit may be determined by the degree of classification coverage, then the type of unit is also displayed (as shown in the figure). If there is sufficient coverage to identify the unit, then the identity of the unit is also displayed.

The decision model uses the perception of the conflict area as the basis for its decisions. The PIRs are also displayed in this picture. The two paths highlighted in Blue indicate that these paths are PIRs for the Blue commander. In addition, five Blue boxes are shown, indicating either NAIs or TAIs. When an enemy unit is attacked in a

TAI, the degree of targeting (acquire) coverage is checked. If the targeting coverage is only 50 percent, then at most 50 percent of the target assets could be engaged at that time.

Appendix C

THE INTELLIGENCE SUBMODEL

This appendix is intended to supplement the discussion of the intelligence submodel found in Chapter Four. Figure 4.6 illustrates the direction of the data flow within the model. We will refer to it in the following discussion.

INDICATORS AND CAPABILITIES

Raw intelligence information is much too high a volume for a one-to-one mapping between a specific observation and a specific information requirement. In fact, hundreds of observations might still not be enough to answer a general question concerning the entire conflict area. The dynamic model does not simulate observations directly, in part because of its lower level of resolution, and in part because single observations are often so unpredictable that a more aggregated approach can actually result in more realistic overall behavior.

On the other hand, it is impossible to take general questions and immediately apply them to a simulated operation. A great deal of processing goes on between the information the commander receives and the signals, images, etc. We have therefore added two conceptual levels: the first (going top-to-bottom) is indicators; the second is signatures. Signatures correspond to groups of observations, and indicators attach specific meanings to one or more signatures.

Coverage, as previously defined, is the capability to make observations. A signature is then the ability to make an observation and the presence of something to observe. (The latter could be a deception or otherwise be erroneous but is usually based on ground truth.) A signature can be either diagnostic (indicating on its own the presence of something that is being looked for) or suggestive (unable to indicate the presence of something unless other signatures are also found). Thus, one or more signatures are assembled to create an indicator in a manner based upon this distinction. Any diagnostic signature provides an indication, while it might take a combination of several suggestive signatures to yield that indication. It is also possible to make the same sort of distinctions—suggestive compared to diagnostic—for the indicators themselves.

THE SENSOR SUBMODEL—GENERATING COVERAGE

The conceptual abstractions of indicators and signatures must eventually be linked with a model of physical phenomena; this is the sensor submodel. In brief, it examines all the sensors in the modeled area, determining their status, operating altitude,

and so on, and combines this information with knowledge of external factors such as weather, terrain, and enemy passive or active countermeasures. The result is a determination of the coverage capability of each sensor, along with a composite map of coverage. The latter map can be thought of as an overlay on top of the operations adjudication submodel's simulated operations area; it indicates how well that area can be seen and by what modes of observation.

Area cover on the ground depends upon the altitude at which a given platform is flown (also, platform speed, orbit pattern, and revisit time). In the case of ground-based collectors, the sensor's antenna height above the ground is used. These parameters are obtained from the databases in the sensor submodel. If the analyst wishes, standard CPFs, i.e., employment parameters according to doctrine, may be used or changed at will to help the analyst understand how variations might affect operations.

The coverage map is used for sensor allocation, and displays of the map are used by the analyst. However, the main representation of coverage in the model is associated with the enemy units themselves; that is, each unit is "painted" with the coverage its adversary can bring to observe it. This coverage is divided into a number of categories and is affected by several conditions, including weather, terrain, and countermeasures.

INTELLIGENCE SUBMODEL IMPLEMENTATION

Like the other submodels, the intelligence submodel is implemented in the RAND-ABEL language. Intercommunication with the other submodels is done primarily through procedure calls. For example, the decision submodel calls specific intelligence submodel functions for each type of PIR and HPT. During generation of its coverage map and the individual coverages of the enemy's units, the intelligence submodel queries the operations adjudication submodel as to the status and location of those assets and units. These queries are a mixture of calls to operations adjudication submodel functions and direct access to that submodel's maps of forces, terrain, and so forth.

The remainder of this appendix describes the specific mechanisms the intelligence submodel uses in these various functions and the various maps and tables it uses to represent intelligence capabilities and allocation. Although little computer code is currently represented in these descriptions, it should be possible to reconstruct the intelligence submodel's functionality from the descriptions given.

Intelligence Submodel Cycles

The intelligence submodel does all of its internal processing in two phases, which are executed on a periodic basis during a run of the dynamic model. The first phase updates the map of coverage and the coverage values for each enemy unit, and the second phase performs allocations based upon scripts or the model's own evaluation of coverage needs. Additional intelligence submodel processing occurs when requests for information are made by the decision submodel—in fact, this processing actually occurs between the other two phases. Thus, a complete model cycle would look like that shown in Figure C.1.

Figure C.1—Intelligence Submodel Cycles

Simulated time passes during the request phase, when the operations adjudication and decision submodels run. Thus, the main phases of the intelligence submodel each act upon a single instant of time, with their results reflecting those changes that would have occurred since they were last executed. This discrete nature of time should be kept in mind during the following discussion.

Updating Coverage—the Sensor Sub-Submodel

The operations adjudication submodel maintains a list of sensors and sensor platforms and their status. By "status" we mean location, velocity, connectivity, operating mode, and so forth. The operations adjudicator performs several functions upon this list:

- Moving space and airborne platforms and their sensors along an ordered path;
- Moving ground sensors along with their associated force units; and
- Attriting sensors and platforms based upon conflict conditions.

The list is then assessed by the sensor performance module within the intelligence submodel (also called the sensor submodel) and used in updating the coverage maps.

In simplified form the algorithm used to do the coverage update looks like this:

1. For [each] sensor [in the sensor list]:
2. If status of sensor is not active then continue [to next sensor].
3. Find location of sensor.
4. For [each] enemy-unit:

   For [each] coverage-type:
5. Increase coverage [in the area appropriate to the sensor] of enemy-unit by coverage-factor of sensor and coverage-type.

Each sensor in the sensor list is examined, one at a time (step 1). In actuality, two sensor "lists" are scanned—the list of friendly units and the assets associated with them and a separate list of airborne platforms. If a sensor is destroyed, disconnected, or otherwise becomes inoperative, no check is made of its effect on coverage (step 2). If the sensor is active, it is located (step 3) and its effect on each type of coverage for each enemy unit is evaluated (4). Although the listed algorithm does not show it, this

coverage can depend upon other aspects of the sensor and its location, such as altitude and terrain, and upon the activities of the unit. This is why the sensor is located before its coverage contribution is determined and added to the appropriate coverage score (step 5).

Numerous actions occur during step 5. Since more than one sensor may be providing a certain type of coverage, the effect of such multiple reports must be reflected. Some types of coverage, such as the ability to identify units visually, might be equal only to the best-quality imaging system available. Other types of coverage, such as direction-finding, might be greatly improved by the presence of multiple sensors of the same type. These effects must be accounted for in step (5), as must effects based on a sensor's location and mode of operation. All this is a function of the sensor submodel, which keeps tables of range and effectiveness by sensor type.

Thus, step 5 can be further broken down:

5a. For [each] enemy-unit [in sensor range]:

5b. Let coverage of enemy-unit and coverage-type be [the] combining-function [for this coverage-type] of coverage-factor of this-sensor and coverage-type, times the terrain-factor of this sensor's location, times the countermeasure-factor of enemy-unit, times the weather-and-smoke-factor of this combination of sensor and unit location.

The combining-function used in step 5b could choose the maximum or could simply add one to a count of effective sensors within the cell. This implies that the value produced will be in units that depend upon the type of coverage involved. However, in the current prototype model it means the probability that a given observation will allow detection, identification, etc., depending upon the coverage type concerned. The overall formula for combining the contribution of various sensors is thus:

$$P(\text{total}) = 1 - \text{PRODUCT}\ (1 - P(\text{each sensor}))$$

This is applied individually to every coverage type for every enemy unit. The synergism between sensors is currently modeled by creating a composite sensor with the combined characteristics, although such synergism should eventually be modeled directly. In the meantime, this formulation implies that more coverage is better (with diminishing returns) and that no additional coverage will make the composite picture look worse than before.

Handling Requests

At the top level, the intelligence submodel presents a set of functions that are called by the decision submodel. These functions accept a variety of parameters and return such aggregate measures as probability of detection (e.g., for a given enemy unit in a given area), observed enemy force strength, and so on. For example, one top-level function might accept the following as arguments:

- A path or cell within the operations adjudication submodel;
- A radius around that path or cell;

- A threshold for enemy strength;
- A threshold for probability of detection;
- A time deadline;
- A force type;
- A force activity;
- An enemy unit ID; and
- The priority of the request.

Not all of these parameters would be required by a given information requirement function, and some of them (e.g., unit type or ID) might simply be given as "any."

The result given by these functions could be any of a number of things. For example:

- Perceived strength of enemy in area (perhaps for a specific force type or activity);
- Probability that the thresholds given have been exceeded (for a given force strength, unit ID, or other qualification);
- Location of unit (or largest mass of enemy forces) within given area and so on. More than one result may be desired for a given area—for example, both the strength and location of forces might be important. In this case, two functions are evaluated in succession.

We discussed indicators and coverage capability above. The information requirement functions call for one or more indicator functions in generating their result, and the indicator functions exploit signatures by combining the coverage maps with ground truth. For example, an information requirement function asking for the probability that the armored strength in a given area is more than a threshold level might perform the following actions:

1. If detectable infantry units in area are greater than strength-threshold times 1.5 and detectable tank units in area are greater than strength-threshold times tanks-per-ED

   Then,

   report [probability of threshold exceeded as] 0.9.

2. Else, if detectable infantry units in area are greater than strength-threshold and detectable tank units in area are greater than strength-threshold times tanks-per-ED times 0.7

   Then,

   report [probability of threshold exceeded as] 0.5.

3. Else, if detectable infantry units in area are greater than strength-threshold times 0.7 and detectable tank units in area are greater than strength-threshold times tanks-per-ED times 0.5

   Then,

   report [probability of threshold exceeded as] 0.3.

4. Else, report [probability of threshold exceeded as] 0.1.

Steps 1–4 would be implemented as a decision table and would include additional possibilities. The indicator functions' units in area and tanks in area in turn scan the list of enemy units and their coverage and count up those that would be detected (or, in other circumstances, located or some other coverage category type).

ALLOCATION

Two modes of allocation are available in the dynamic model. One of these, called "scripted" mode, allows planned allocations of one or more sensor platforms to take place at those points where conditions require them. (The term "script" tends to suggest an oversimplified view of things, since in actuality a complex set of conditions can serve as the trigger for a given allocation plan—analogous in some ways to the decision submodel's "plan segments." We found that analysts tended to prefer the script when attempting to keep variations in the scenario to a minimum.) The other allocation mode is called the "automated" mode, which is somewhat simplistic at this point but provides a more flexible allocation capability. We describe the latter here.[1]

Automatic allocation of intelligence-gathering assets is done on the basis of coverage requirements. (See the operations adjudication submodel for script-based allocation.) Each indicator requires one or more types of coverage, and each intelligence-gathering asset provides one or more types of coverage. Thus, a logical point at which to perform allocation is during the intelligence submodel's processing of indicators and of signatures. Where a deficit in coverage exists, an attempt is made to allocate resources to cover that deficit.

The following example indicator function illustrates how allocation is triggered in step 2:

1. For enemy-unit in unit-list:

   If enemy-unit is in area

   Then, Increase units-seen by detectability of enemy-unit times ED-strength of units.

2. For cells in area:

   If coverage of area is less than minimum-coverage

   Then, Perform Request-coverage using area as location, detect as coverage-type, and minimum-coverage as coverage.

---

[1]In our description so far, we have traversed the intelligence submodel from the commander's information needs to the actual intelligence assets on or over the operations area. The positioning and operating mode of these assets has direct bearing on how well signatures can be obtained. Thus, in the automated mode, the dynamic model allocation is based upon the particular coverage capability required. This is a fairly simple process and involves examining the list of the commander's information requirements from highest priority to lowest and assigning (or possibly preempting) assets to fill any gaps in the required coverage. In terms of implementation within the intelligence submodel, the allocation process is initiated simultaneously with the requests for information. However, this does not exclude the modeling of delays in deployment, transmission, or processing. It simply means that the need for allocation is detected at the time the request for information is made.

The operations adjudication submodel maintains a list of active sensors and sensor groups; this is the list used in coverage processing. In addition, a list of sensors and sensor groups can be allocated to provide coverage. Actually, this is the same list as the first but with the listed assets being marked as "available" and otherwise inactive. When the allocation process is triggered, as in the above example, allocation is performed in the following manner:

For [each] sensor [in sensor table]:

1. If status of sensor is in-transit and destination of sensor is location

   Then,

1a. Temporarily increase coverage by coverage-capability of sensor

   For [each] sensor [in sensor table]:

1b. If status of sensor is available or

1c. (status of sensor is active and priority of request is greater than priority of sensor)

2. Then, if coverage ability of sensor is appropriate

   Then,

3a. Allocate sensor, preempting if necessary.

3b. Temporarily increase coverage by sensor's contribution.

3c. If coverage is above threshold-required

   Then,

   Allocation finished.

   [end of loop].

4. Add to allocated coverage, and readjust actual coverage.

In brief, each sensor is considered. If (step 1a) it is already in transit to the desired location (or it is on a path that will carry it there at an appropriate time), its eventual contribution to coverage is temporarily added (for the duration of the allocation step). If the sensor is available (step 1b) or preemptible (step 1c), the sensor is tested (step 2) to see if it is able to provide the coverage needed. If it can provide that coverage (or make a reasonable contribution to it), it is allocated (step 3a) and its eventual contribution to coverage is temporarily added to the coverage map (step 3b). If enough coverage will then be available, the allocation process is finished for this particular coverage type (step 3c). Any temporary changes to actual coverage figures are eventually removed (step 4), since the allocated coverage will not be available until the appropriate platform is in position, or at least until the next coverage cycle of the intelligence submodel if no platform movement is required.

Step 2 is actually fairly complicated, since "appropriate" coverage depends upon how quickly the sensor can be brought into position as well as upon its technical capability (which must be within at least a factor of cov-frac of that required). Time requirements, if specified by the original information requirement, are used to make this determination. Otherwise, time requirements are based on the decision submodel's planning cycle (i.e., this is the default). Thus, step 2 can be broken down as follows:

2a. Look up cov-frac in table based upon coverage-type.

2b. Let time-to-dest be launch-time of sensor plus (distance to area of interest minus range of sensor) divided by speed of sensor.

2c. If requested-time is unspecified.

Then, let requested-time be decision-cycle-time.

2d. If coverage-capability of sensor in this coverage-type is above threshold-required times cov-frac

and

requested-time is above time-to-dest

Then, allocate sensor.

Key to the operation of this mechanism is the temporary addition to the coverage maps of the contribution of any just-allocated or in-transit sensor. This contribution is not counted during the coverage phase of the intelligence submodel but is necessary to prevent redundant allocations during the allocation phase. See Figure C.2.

SETTING UP THE INTELLIGENCE SUBMODEL

One major objective of the OPVIEW project was to create a model that was easily adaptable for a variety of combat or noncombat situations, intelligence assets, and decisionmaking philosophies. This was a primary reason why the RAND-ABEL language and environment were selected for implementation. Flexibility has its price, of course, and in this case it means that an analyst needs to review and

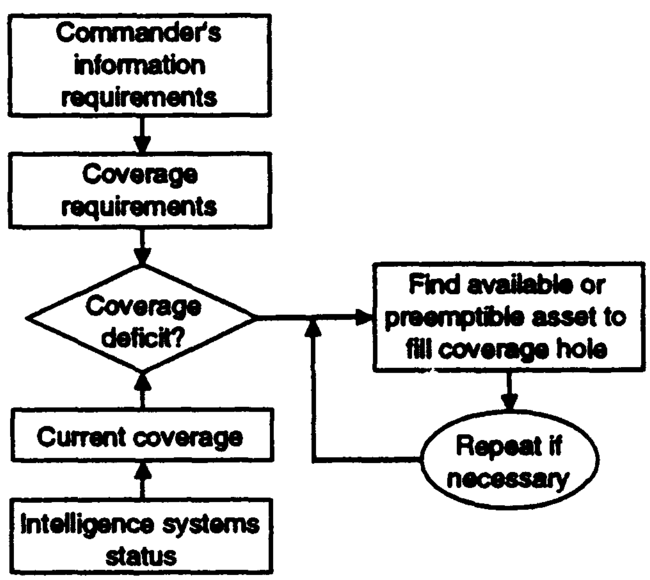

Figure C.2—Automatic Intelligence Asset Allocation

perhaps revise the various tables that make up the model. This section describes this process for the intelligence submodel.

Context—Setup of the Other Models

The operations adjudication and decision submodels will generally require review and revision along with the intelligence submodel. In fact, the operational plan used in configuring the decision submodel is generally a good starting point for overall configuration of the dynamic model system. Even though a given analysis might be focused on particular IEW/TA assets, the operational plan must be one that might involve those assets and will embody some basic assumptions as to how intelligence will be employed. However, the decision submodel is a good starting point because of the central position taken by the information requirement functions. These functions are logically part of both the decision and intelligence submodels and thus are a focal point of OPVIEW's multidimensional methodology. Which functions are used—and just how they are used—depends upon the information requirements of the plan.

It is possible that one or more information requirement functions will not yet exist, especially while the dynamic model is just beginning to be used. A copy of one existing function can usually be used as a template, since the new requirements most likely will affect only things such as the area being examined, or a shift in the combination of indicators being observed. In turn, new indicator functions might be required. These, too, will most likely be similar to existing functions and might differ only in the type of coverage required or the particular force type considered.

For a preexisting operations vignette and plan, a simple review of the information requirement functions associated with that scenario and its plans may be all that is required. In any event, once all necessary information requirement and indicator functions are in place, the "bottom half" of the dynamic model system should be considered: lists of assets and their characteristics. In particular, the organic IEW/TA assets of combat (or noncombat) units need to be considered while the units themselves are being configured and located. Logistical and communications support needs to be considered. And reasonable estimations of the enemy assets faced need to be made in considering how IEW/TA assets are "packaged." At this point, the IEW/TA assets themselves can be configured.

Configuring IEW/TA Assets

Although the dynamic model system as a whole should be viewed from a top-down perspective, the process of configuring the IEW/TA assets represented is somewhat of a bottom-up process. A collection system or grouping of systems is named, then the various performance factors and attributes for that system or systems are added. Finally, if a scripted allocation scheme is being used, the paths, orbits, and destinations of the sensors are set up, and the conditions for activation of a given script are specified.

Setting Up the Sensor/Platform Tables

There are several interlinked data and decision tables in the intelligence submodel, which specify the various parameters and groupings of IEW assets. The diagram in Figure C.3 shows the relationships between the tables involved:

The sensor list includes all collectors within the dynamic model, by type, quantity, location, destination, and status. All collectors of a type (including same type sensor platform and payload) are assumed to have identical characteristics, and so each type has a single line in the sensor types table, regardless of the number of such collectors (if any) in the sensor list. The sensor types themselves form a RAND-ABEL enumeration, which then indexes arrays holding the attributes given in the stacked boxes of the diagram (see Figure C.3). The collection probabilities for a given type of collector are specified for each of eight coverage types as listed below, and weather and terrain adjustments contain factors used to adjust these probabilities for the anticipated conditions. Sensor performance attributes provide range and other such information. The countermeasures employment activities are used to determine just what countermeasures a given unit activity implies; this knowledge is then used to apply countermeasures employment factors to further adjust coverage. Finally, the timeliness requirement for the various coverage modes, given the response speed of a given sensor, is specified in timeliness factors for activities.

Adding or modifying a collection asset involves modifying the above tables, all located in the "Intel-init.A" source file, and placing any new or changed type names in the intelligence submodel's "Dict/type.D" dictionary file.

The eight coverage types are contained in the following list:

- Detect;
- Generally locate;

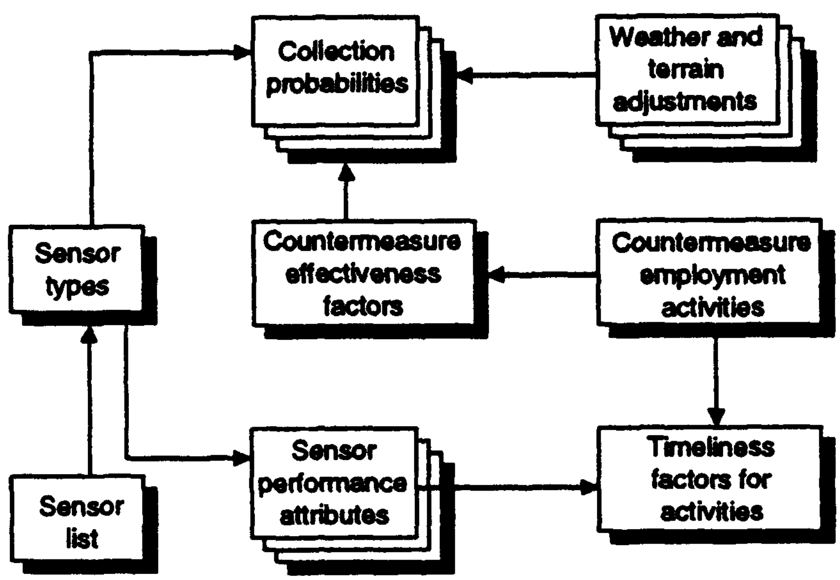

Figure C.3—Relationship Between Sensor and Collection Modifier Tables

- Precisely locate;
- Classify;
- Identify;
- Track;
- Acquire; and
- Assess poststrike residual operational capabilities (including BDA).

Adding Information Requirements

Unfortunately, the representation of information requirements and indicators cannot be entirely table-driven. However, the logic involved in writing these functions is generally not very difficult, and existing functions can frequently be changed on the margin to create new functions. Above, we described some of the mechanisms involved and gave some pseudocode examples.

Creating a New Indicator Function

The "Indicator.A" file contains all indicator functions, and the declarations for these functions are in the "Dict/func.D" file. Part of the work in a given indicator function is simply a matter of determining which cell or cells in the coverage maps and ground truth need to be considered. This can range from looking only at an explicit point to examining an entire area or path. Examples of point, area, and path indicator functions are already present, so this part of the code can more or less be copied. It will generally examine each potential threat entity in the "troop list" (i.e., the list of units); check to see if it is in the defined cell, area, or path; determine if it is of the appropriate type or contains assets of the appropriate type (e.g., tanks); then execute the coverage—evaluation code ("signatures") for each "hit," if any.

Depending upon the particular indicator, the coverage-evaluation code might first check to see if coverage exceeds a threshold, and if it does, report back a yes/no evaluation or the quantity of enemy asset seen (which would be a function of ground truth and the coverage value). More than one type of coverage might be used, especially for assets that are really a group of different entities or when the maximum quality of available information (e.g., Detect compared to Identify) is an important result.

For each coverage type used, an expected minimum of coverage quality should be tested for; the minimum might be zero if other forms of coverage exist, making it unnecessary. If coverage has fallen below the threshold, the allocation-request function for the needed area and coverage type should be called.

Creating a New Information Requirement Function

Satisfying an information requirement involves the detection of one or more indicators. If a single indicator is involved, the information requirement function might simply set up a call to the appropriate indicator function (defining area, capability required, threat entity, thresholds, and so forth) and return the result. Many infor-

mation requirement functions involve more than one indicator, however, and thus need to define the relationship between them. This is generally done via a decision table (see Table C.1), as in the following simple information requirement function:

> Let troop-indicator be the report from Infantry-EDs-in-area using area as area, and 0.75 as probability.
>
> Let armor-indicator be (the report from Tank-EDs-in-area using area as area, and 0.75 as probability) plus (the report from Mech-EDs-in-area using area as area, and 0.75 as probability).

The decision table in this example reports the presence of a division in the area if there are at least 0.5 tank and mech EDs or 1.0 infantry EDs. Much more complex decision tables are possible, of course.

Care must be taken to ensure that the actual information requirement needed by the decision submodel and its plan match the information obtained by the information requirement function. The result could be a simple yes/no, as illustrated here, or could be a confidence level, or an ED value, and so forth. Care should also be taken to ensure that a new function is general enough that it might be used for other plans or operations vignettes.

Table C.1

Decision Table

troop-indicator	armor-indicator	is-division-in-area
>1.0	—	Yes
—	>0.5	Yes
—	—	No
Exit reporting is-division-in-area		

Appendix D

OPERATIONS ADJUDICATION SUBMODEL

This appendix supplements the discussion of the operations adjudication submodel presented in Chapter Four. The operations adjudication submodel keeps ground truth for the simulation, maintaining the maps and lists of troops and sensor platforms. It moves troops and platforms as their destinations are changed by the decision submodel or the user, adjudicates direct and indirect fire combat, and writes text and graphics logs of the action.

The following sections give an overview of the submodel's structure and execution, then describe the workings of each major function.

MODEL DESCRIPTION AND EXECUTION SEQUENCE

Table D.1 lists the modules that make up the operations adjudication submodel in their order of execution and briefly describes their function.

Table D.1

Operations Adjudication Submodel's Modules

Module	Description
Update Troop Activity	Determine the activity of each ground unit
Update Platform Activity	Determine the activity of each collection platform
Move Troops	Move each ground unit
Move Platforms	Move each intelligence platform
Update Troop Activity	Change activity as required by movement
Update Platform Activity	Determine the activity of each collection platform
Assess Indirect Fires	Indirect fire from ground units on the map
Assess Platform Losses	Losses to collection platforms
Assess Operations	Equipment losses and whether the cell is taken
Log Graphics Data	Write data used by the MAPVIEW graphics program

MODULES, FUNCTIONS, AND FILES

Table D.2 gives the main RAND-ABEL functions of interest in each of the referee modules and the files in which they are found. These files are in the directory Src/Force-A/Referee.

Table D.2

Referee Modules and Files

Referee Module	Primary Functions	Files
Update Troop Activity	Update-activity	troop.A
Move Troops	Deploy-troops	troop.A
Assess Combat	Cell-combat	troop.A
Assess Combat	Determine-cohesion	troop.A
Assess Indirect Fires	Troop-indirect-fire	troop.A
Assess Combat	Kill-troop	troop.A
Update Platform Activity	Update-platform-activity	platform.A
Move Platforms	Move-platforms	platform.A
Assess Platform Losses	Determine-platform-losses	platform.A

MAPS

The map is a two-dimensional grid of square cells. All terrain features, environmental conditions, area coverage, unit position, and their activities and status are designated, and aggregations of unit data are kept in two-dimensional arrays that conform to the digital map.

These are terrain data arrays, initialized in the file map-init.A.

Terrain-map	terrain
Highway-map	highways
River-map	rivers
Path-map	movement paths for troops
Defense-map	constructed defenses
Urban-map	urbanization
Max-atk-ED-map	maximum attacking EDs allowed
Max-def-ED-map	maximum defending EDs allowed
Min-def-ED-map	minimum defending EDs required to hold the cell

These arrays contain model data that are updated as the model runs.

Troop-map	troop indexes
Platform-map	platform indexes
ED-map	total blue/red EDs
DF-ED-map	total blue/red direct fire EDs
ID-ED-map EDs	total blue/red indirect fire
ED-loss-map	total blue/red ED losses this time-step
Maneuver-unit-map	total number of maneuver units
Fraction-taken-map	fraction of the cell occupied by the attacker
Battle-map	type of battle
Combat-map	presence of combat
Display-map	display of the most interesting item in each cell

TROOPS

These arrays form the list of ground units in the model. Each troop has a unique index through which its data in each array are referenced. Initial values are set in the file unit-init.A.

These data describe the troop and its equipment.

Troop-unit	unit type
Troop-side	blue/red side
Troop-name	string name
Troop-parent-name	string name
Troop-#-tank	number of tanks
Troop-#-mech	number of mechanized vehicles
Troop-#-inf	number of infantry
Troop-#-arty	number of artillery
Troop-arty-type	type of artillery
Troop-#-ADA	number of air defense artillery
Troop-#-helo	number of attack helicopters
Troop-tank-ED	ED score of tanks
Troop-mech-ED	ED score of mechanized vehicles
Troop-inf-ED	ED score of infantry
Troop-arty-ED	ED score of artillery
Troop-ADA-ED	ED score of attack helicopters
Troop-ED	total ED score of tanks
Troop-orig-ED	total original ED score
Troop-cohesion	level of cohesion
Blue's Troop-sensor	list of blue sensors
Red's Troop-sensor	list of red sensors

These data constitute orders given to the troop by the user or decision submodel.

Troop-mission	assigned mission
Troop-path	path index assigned to
Troop-dest-row	destination row index
Troop-dest-col	destination column index
Troop-target-row	indirect fire target row index
Troop-target-col	indirect fire target column index
Troop-target-type	indirect fire target type
Troop-target-unit	indirect fire target unit type
Troop-target-activity	indirect fire target activity
Troop-load	indirect fire load fired
Troop-support-troop	index of unit to support with indirect fire

These data describe the troop's current position and status.

Troop-lat	latitude
Troop-lon	longitude
Troop-row	current location—row index
Troop-col	current location—column index
Troop-facing	compass direction facing
Troop-activity	current activity
Troop-hour-activity-begun	time the current activity was started
Troop-hour-last-engaged	time the unit last fought
Troop-hour-cell-entered	time the current cell was entered

Troop-kms-moved-in-cell	number of km moved through the current cell
Troop-stopped-til-hr	time until which the unit cannot move
Troop-targetability	level of intelligence against unit
Troop-next-row	next row index that will be entered
Troop-next-col	next column index that will be entered
Troop-last-row	last row index that was entered
Troop-last-col	last column index that was entered

SENSOR PLATFORMS

These arrays form the list of sensor platforms in the model. Each platform has a unique index through which its data in each array are referenced.

These data describe the platform and its sensor and are initialized in the file unit-init.A.

Blue's Platform-sensor	blue sensor type
Red's Platform-sensor	red sensor type
Platform-vehicle	vehicle type
Platform-orig-lat	originating latitude
Platform-orig-lon	originating longitude
Platform-speed	km/hour speed
Platform-%-availability	percentage of time available
Platform-side	Blue/Red side
Platform-regenerate-hours	hours to regenerate between missions

These data constitute orders given to the platform by the user or decision model.

Platform-dest-list-row	list of destination rows
Platform-dest-list-col	list of destination columns
Platform-dest-list-time	list of hours to loiter at each destination

These data describe the platform's current position and status.

Platform-activity	current activity
Platform-hour-activity-begun	time the current activity was started
Platform-dest-row	destination row currently moving toward
Platform-dest-col	destination col currently moving toward
Platform-curr-lat	current latitude
Platform-curr-lon	current longitude
Platform-curr-row	current location row
Platform-curr-col	current location column
Platform-orig-row	current location row
Platform-orig-col	current location column
Platform-last-lat	latitude last at
Platform-last-lon	longitude last at
Platform-dest-list-index	index of current destination in the list
Platform-surviving	percent effective due to damage

GROUND COMBAT DATA FLOW

Figure D.1 shows the main variables used in ground operations adjudication and the functions each is invoked from.

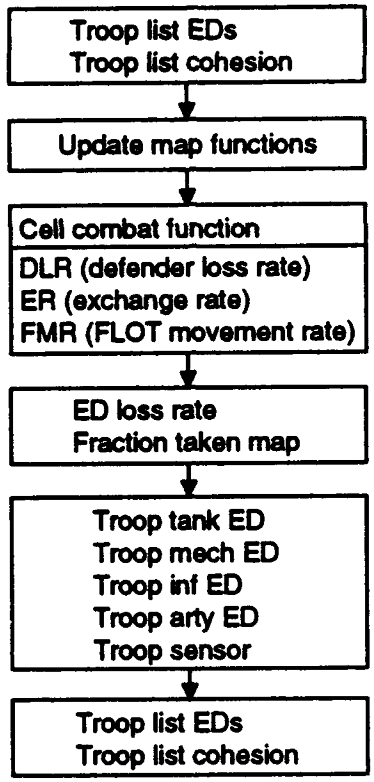

Figure D.1—Ground Operations

FUNCTION UPDATE-ACTIVITY

This function updates the activity of each unit, as illustrated in Table D.3. The function "in-combat" specifies whether there is combat in the unit's cell, at-dest whether it is at its destination, and "hours-doing" how long it has been engaged in its current activity. Note that the last, default row leaves the activity unchanged.

If a troop's activity changes, the time begun is recorded and a statement written to the log.

FUNCTION DEPLOY-UNITS

This function moves deploying units by first calculating the speeds of all moving units, then moving each in turn one cell at a time.

Speed is calculated from the data in Table D.4 by multiplying a kph value by a factor for the urban buildup in the cell. The factor "on-highway" indicates whether the unit

Table D.3

Activity Update of Units

Activity	Mission	In-combat	At-dest	Hours-doing	Unit	New-activity
—	Move	Y	N	++	—	Disengage
Disengage	—	—	—	>1	—	Tac-move
—	>=Feint	Y	—	++	—	Assault
—	—	Y	—	++	—	Defend
>=Admin-move	—	—	Y	++	—	Arrive
Arrive	—	—	Y	>2	—	Wait
<Pack	—	—	N	++	—	Pack
Pack	—	—	N	>3	Abn	Air-move
Pack	—	—	N	>3	Asslt	Air-move
Pack	>=Feint—	—	N	>3	—	Tac-move
Pack	—	—	N	>3	—	Admin-move
—	—	—	—	++	—	activity

Table D.4

Unit Deployment Speed According to Terrain, Highways, and Activity Type

Unit	Terrain	Highway	Activity	Kph
Inf	<=mixed	—	—	4
Inf	<=sandy	—	—	2
Inf	closed	—	—	1
—	—	—	Air-move	300
—	—	Y	Admin-move	45
—	<=mixed	N	Admin-move	25
—	<=sandy	N	Admin-move	10
—	closed	N	Admin-move	2
—	—	Y	Tac-move	22
—	<=mixed	N	Tac-move	12
—	<=sandy	N	Tac-move	5
—	closed	N	Tac-move	1
—	—	—	—	1

is traveling on a highway in the current cell. The terrain types are ranked in the following order: open, mixed, rolling, wadi, sandy, closed, airfield, and water. In Table D.4, an element "<=mixed" means either open or mixed terrain, and "<=sandy" means rolling, wadi, or sandy terrain. The first row of Table D.4 is read "If the unit type is infantry, and the terrain type is mixed or open, the speed is 4 km per hour." If the first row is not true, then there is an implied "else" statement and then the next row is tested. For example, if the first row is not true, the next row in the table is read "Else, if the type unit is infantry and the type terrain is rolling, wadi, or sandy, then the speed is 2 km per hour." This type of RAND-ABEL table makes it very easy to partition the space and quickly define a unit's speed by type of unit, type of terrain, use of highway, and unit activity. Table D.5 includes an additional multiplier on a unit's movement rate as a function of the degree of urbanization.

Next, multiple passes are made over the troop list, each pass moving any troops with movement remaining into the next cell.

Table D.5

Unit Deployment Speed According to Terrain and Urbanity

Urbanity	Activity	Mult
—	Air-move	1.0
urban	—	.6
suburban	—	.8
—	—	1.0

If the troop is assigned a path and is on that path, the next cell is the cell on that path that is closest to its destination. If it is assigned a path but is not on it, the next cell is the cell closest to the path. Otherwise, the next cell is the cell closest to its destination. If, for some reason, the next cell chosen is the same cell the troop is in, movement is stopped for the turn and a warning message logged.

The distance to the next cell is calculated (either an orthogonal or diagonal move) and checked against the troop's remaining movement. If unable to enter the next cell, the troop's progress through the current cell is recorded, otherwise the bookkeeping for entering a new cell is done.

If the new cell is the troop's destination, the troop stops and its destination is cleared, and if the new cell contains enemy troops, the troop simply stops and checks its mission to determine the type of battle assessed. A message is logged in each case.

FUNCTION CELL-COMBAT

This function determines the outcome of combat in a cell containing troops of each side. See Table D.6.

Table D.6

Opponent's Mission and Battle Type

Atk-mission	Def-mission	Engagement
<Feint	Move	Meeting
>Defend	Move	Rout
>Defend	>Defend	Meeting
Main-attack	Defend	Battle
Main-attack	Delay	Def-withdraw
Spt-attack	Defend	Battle
Spt-attack	Delay	Def-withdraw
Feint	Defend	Attack-withdraw
Feint	Delay	Skirmish
<Feint	<Feint	No-battle
		[Move accounted for above]
—	—	No-battle

The defending side is chosen to be the side with a troop with the Defend mission, or failing that, the smaller side in EDs. The overall mission for troops on each side in

the cell is chosen as the highest-ranked mission of any individual troop (in the order given in the enumeration definition).

The battle type is determined by the missions of both sides. The types of missions are ranked as follows: move, delay, defend, feint, support attack, main attack. A table entry such as "<Feint" means move, delay, defend, or feint. The first two rows are read as follows: "If the attacker mission is move, delay, or defend, and the defender mission is to move, then a meeting engagement takes place; else, if the attacker's mission is a feint, supporting attack, or main attack, and the defender's mission is to move, then the defender is routed." If neither condition is true, then each row is tested in sequence until the first row that is true is triggered. Note that the default type battle is no battle.

In a meeting engagement, the attacking and defending sides are switched if the attacker is not the larger side in EDs.

The attacker-over-defender force ratio is calculated, including terrain factors shown in Table D.7 for the attacker and defender.

The outcome of the hour's battle is determined from the battle type, attacker's mission, force ratio, and number of hours the defender has been in place. See Table D.8.

Table D.7

Attacker-Defender Force Ratio and Terrain Types

Terrain	Def-ed-mult	Attack-ED-mult
mixed	0.87	0.75
rough	0.75	0.50
closed	0.62	0.25
—	1.00	1.00

Table D.8

Attacker's Mission

Engagement	Attack-mission	FR	Hours in place	Engagement-outcome
Battle	—	<1.0	>4	Atk-break
Battle	—	<1.0	<4	No-move
Battle	Spt-attack	<1.5	>4	Atk-break
Battle	Spt-attack	<3.0	—	No-move
Battle	Spt-attack	<4.5	<8	Def-forced
Battle	Spt-attack	>4.5	—	Def-forced
Battle	Main-attack	<2.5	—	No-move
Battle	Main-attack	<3.5	<8	Def-forced
Battle	Main-attack	>3.5	—	Def-forced
Battle	—	—	—	No-move
Battle	—	↔	↔	No-move
Att-with	—	↔	↔	Atk-break
Def-with	—	↔	↔	Def-forced
No-battle	—	↔	↔	No-move
Meeting	—	<1.5	↔	No-move
Meeting	—	>=1.5	↔	Def-forced
Skirmish	—	↔	↔	No-move
Rout	—	↔	↔	Def-forced

Defender loss rate (DLR) and exchange rate (ER) are calculated from approximations to Lanchester equations selected by battle type, outcome, and attacker's mission. See Table D.9.

Table D.9

Defended Loss Rate

Engagement	Engagement-Outcome	Attack-mission	DLR	ER
Battle	Atk-break	—	(.140 * FR)/(FR + 30)	(15 / (FR + 2.0))
Battle	No-move	—	(.140 * FR)/(FR + 30)	(12 / (FR + 2.0))
Battle	Def-forced	—	(.160 * FR)/(FR + 30)	(10 / (FR + 2.9))
Meeting	—	Move	(.10 * FR)/(FR + 30)	(1.5 / (FR + 0.5))
Meeting	—	>Defend	(.21 * FR)/(FR + 30)	(1.5 / (FR + 0.5))
Rout	—	>Defend	(.21 * FR)/(FR + 30)	(1.5 / (FR + 0.5))
Def-with	—	Main-atk	(.098 * FR)/(FR + 3.6)	(0.5 / (FR + 0.5))
Def-with	—	Spt-atk	(.098 * FR)/(FR + 3.6)	(9.0 / (FR + 1.5))
Atk-with	—	Feint	(.10 * FR)/(FR + 6.0)	(3.6 / (FR + 1.8))
Skirmish	—	Feint	(.06 * FR)/(FR + 6.0)	(3.6 / (FR + 1.8))
No-battle	—	++	0	0

FLOT movement rate (FMR) is also determined from the engagement type and outcome. In the case of defender withdraw, the cell is vacated. See Table D.10.

Table D.10

FLOT Movement Rate

Engagement	Engagement-Outcome	FMR
Battle	Def-forced	3
Meeting	Def-forced	(2 * FR)
Def-with	—	Cell-size
—	—	0

The ED loss and loss rates for each side are calculated and a summary of the combat logged. The function Distribute-ED-losses is performed to distribute the ED loss among the equipment of all troops in the cell. If the FLOT movement within the cell is greater than the cell size, the attacker takes the cell.

FUNCTION DISTRIBUTE-ED-LOSSES

Given the total ED loss rate to all troops on a side in a cell, this function distributes those losses over the equipment of individual troops. See Table D.11.

The loss rate is weighted for each equipment type by the factors shown in the table.

Table D.11

ED Losses

Engagement	Tank-mult	Mech-mult	Inf-mult	Arty-mult
—	1.5	1.5	1.0	0.5

Troop sensors are lost at the unweighted loss rate.

FUNCTION TROOP-INDIRECT-FIRE

This function assesses the results of a single troop's indirect fire. See Table D.12.

The target of a troop's indirect fire is either an individual troop, or a cell with activity and unit type as qualifiers. If a cell is specified, the largest troop matching the qualifiers is chosen.

Allowed range is based on the artillery type.

Table D.12

Artillery Range

Artillery	Km-range
MLRS	100
LR	40
MR	20
—	10

Effects are specified as a number of vehicles (or pieces of equipment) killed per ED of artillery fired. See Table D.13.

Table D.13

Enemy Kills, by Unit Type Credited to Artillery

Arty	Target type	Terrain	Tactic	Tank kills	Mech kills	Inf kills	Arty kills
—	Armor	—	—	40	10	5	5
—	Mech	—	—	10	40	5	5
—	Arty	—	—	0	0	5	40
—	Inf	—	—	5	10	40	5
—	—	—	—	10	10	10	10

These numbers are multiplied by the number of artillery EDs fired and the rate of intelligence coverage in the cell. The total losses are then assessed against the target troop's equipment and EDs.

FUNCTION DETERMINE-COHESION

This function determines the rate of cohesion for each troop, representing the effectiveness of the unit in combat accounting for disorganization and other damage to command and control. It is based on the fraction of the troop's original ED strength remaining and the number of hours out of combat. See Table D.14.

Note that at less than 25 percent strength the unit will be considered as destroyed.

Table D.14

Enemy Cohesion as a Function of Combat

%-strength	Time-since-combat	Cohesion
<0.25	++	0
>=0.85	++	1.00
>=0.70	>=8.0 [hrs]	1.00
>=0.70	++	0.75
<0.70	>=12.0	1.00
<0.70	>=8.0	0.75
<0.70	>=1.0	0.50
++	++	1.00

FUNCTION UPDATE-PLATFORM-ACTIVITY

Functions are used to update the activity of each platform, according to Table D.15. At-dest specifies whether the platform is at its destination, at-orig whether it is at its origin, and hours-doing how long it has been engaged in its current activity. Next-dest indicates that the next destination must be taken from the destination list (when leaving orbit). At the end of its destination list, the platform returns to its origin. Note that the last default row leaves the activity unchanged.

Table D.15

Sensor Platform Activity

Activity	At-dest	At-orig	Hours-doing	New-activity	Next-dest
Regenerate	—	—	>regen-hr	Wait	—
Wait	N	—	++	Move	—
Move	Y	Y	++	Regenerate	—
Move	Y	—	++	Orbit	—
Orbit	—	—	>dwell-hr	Move	Y
—	—	—	++	activity	—

Function Move-Platforms

This function calculates the new cell position of moving platforms. It converts current and destination cells into lat/lon coordinates, calculates the new lat/lon position of the platform on a straight line between them, and then reconverts the lat/lon position into a row/column cell position.

Function Determine-Platform-Losses

This function determines the losses to platforms that are in a threat environment. See Table D.16.

Threat level is assessed based on the vehicle type, activity, and kilometers distant from the nearest enemy troop.

Table D.16

Sensor Platform Losses Resulting from Threat Environment

Vehicle	Activity	Distance	Threat
—	>=Move	<=10	High
—	>=Move	<=20	Med
—	>=Move	<=40	Low
—	—	—	—

Threat level translates into a loss rate (0–1.0). If the stochastic-platform-losses option is set, then this rate is taken as a probability that the platform is destroyed and a determination made, otherwise it is subtracted from the survival level of the platform. See Table D.17.

Table D.17

Sensor Platform Loss Rate

Threat	loss-rate
High	.3
Med	.15
Low	.05
—	0

Appendix E

DATA REQUIREMENTS AND SOURCES FOR THE OPVIEW MODELS

Obviously, a model's study results depend on the quality of the data used as input. Several kinds of data are required for both the static and the dynamic models. For both models the following kinds of data are required about each collection system:

- System area coverage capability (e.g., map dimensions) over time;
- Capability of each system, when deployed, to detect, locate (generally or precisely), classify, identify, track, or assess the operational status of one or more threat entities; and
- Limitations to coverage because of topography (according to types of terrain in the region), weather restrictions on platform operations and the sensor's detector, and active or passive countermeasures, e.g., smoke, jamming, camouflage, and concealment.

The dynamic model requires the following additional data:

- Red and Blue force unit types, quantities, and strengths in EDs; and
- Expected loss rates, over time, of collection systems according to threats in the region.

Because the static model does not simulate operations, all the data needed to describe force-on-force activities and for adjudicating the results of operations are not required.

Since the dynamic model can employ an unlimited number of tables containing data, theoretically it would be a simple matter to change lines of code in one or more of the existing tables or completely replace some or all with new ones. However, much more is involved, because when the analyst adds new forces or IEW/TA systems, the operating characteristics for them are also required, as well as the range of effects of environmental and operational constraints, and the rules for employment.

ARMY SOURCES OF DATA

As mentioned in Chapter Two, some of the raw values for the CPFs used in the OPVIEW project were provided by the U.S. Army Materiel Systems Analysis Activity (AMSAA). Other values were developed by RAND analysts and Army Fellows at RAND and serve as placeholders, enabling the models to run to test and calibrate their internal operations. The Army (or other users of the models) can replace the

data in the models' current tables with more reliable data when they become available.

DoD SOURCES OF DATA

The DIA *Handbook on Intelligence* systems (DIA, 1987) was the main source of data for the operating characteristics of national, Air Force, and Navy collection systems.

The DIA was also the source of data on non-U.S. forces and intelligence systems; however, we did not apply Red collection systems comprehensively. For a thorough analysis of Red and Blue operations, it would be necessary to include in the models' tables all of the important characteristics of each Red force to be studied. Although we did employ Soviet Red forces and the characteristics of some of their collection systems for the study requested, in the summer of 1989, by LTG Eichelberger, the DCSINT, since that time there have been many political and military changes in the world. For future contingency studies using the dynamic model, it will be necessary to develop tables containing system characteristics and system rules for a variety of potential Reds. We view this work as essential and believe it should be part of a continuing effort by the DIA, together with the Services. Some other related tasks for developing and maintaining databases for both Red and Blue forces are:

- Verification of the data; and
- Periodically automatically providing regular updates to the models' users.

SOURCES OF VALUES FOR THE DYNAMIC MODEL'S TABLES

The values in the tables are obtained from subject matter experts and military studies based upon historical operational experience, scientific and physical evidence, and combat simulations. Currently, efforts are being made to "calibrate" or verify the model's tables by replacing our educated guesses, which temporarily served as placeholders to test the model's internal operations. The principal sources for these data are: the Department of the Army Staff (Deputy Chief of Staff for Operations and Plans and Deputy Chief of Staff for Intelligence), U. S. Army Intelligence and Security Command (INSCOM), U.S. Army Intelligence Agency, U.S. Army Intelligence Center, the Combined Arms Center, materiel developers, AMSAA, AMC (PEO-IEW), FORSCOM unit commanders, and TRADOC system managers. RAND Army Fellows working on the OPVIEW project have been extremely helpful in obtaining much of the data for these tables from the various agencies. The subjective transfer function approach to providing validatable data is described in Appendix F.

TABLES

With the exception of the tables for the intelligence and sensor submodels that pertain to NATO, U.S., and Soviet forces, and IEW/TA assets for them, much of the data for the required tables are still not available. The tables' structures are present and provide valid outputs to other tables for intramodel connectivity purposes, but the data in them are mostly placeholders and must be replaced with valid data to be provided by Army experts.

THE SUBJECTIVE TRANSFER FUNCTION APPROACH FOR OBTAINING VALIDATED SUBJECTIVE MEASURES OF COMPLEX SYSTEMS

The STF method[1] is an approach to measuring effects of system factors on their outcomes using human judgments. Measures are derived from judgment theories (STFs) that have passed validation tests. Major features of the STF approach are outlined below:

- Used in complex system analyses
- Factors defining a complex system (e.g., military intelligence) are:
  - Selected in conjunction with system experts
  - Hierarchically structured
- Factors are manipulated in judgment experiments
  - Manipulated factors form scenarios to which experts respond
  - Experts' responses are used to test judgment theories that describe how factors affect judged system outcomes
  - The STF is the judgment theory that passes its validity tests
- STFs serve to measure effects of factors on outcomes within and external to the system.

Factors defining a system are selected in conjunction with system experts' judgments and are hierarchically structured to represent the system under investigation. The approach incorporates the testability features of algebraic modeling, developed by psychologists, which includes functional measurement (Anderson, 1970, 1981), conjoint measurement (Krantz and Tversky, 1971; Krantz et al., 1971), and extensions to these approaches (Birnbaum, 1974; Birnbaum and Veit, 1974a, 1974b). In the algebraic modeling approach to subjective measurement, judgment theories in the form of algebraic models are postulated to explain experts' judgments. In complex systems that consist of a variety of processes, different groups of experts typically know about different aspects of the system. The theory that passes its explanatory tests for a particular expert group is the STF or underlying judgment theory for that group. The STF for each expert group measures the effects of system capabilities on judged outcomes. The set of STFs across expert groups functionally interlink to produce an overall system effectiveness measure. The interlinking function feature (illustrated in Figure F.1) eliminates the problem of using assumed but untested rules for aggregat-

[1] Veit et al., 1981, 1982, 1984.

ing across system processes found with other approaches to complex system analysis.

Figure F.1 depicts a three-tiered abbreviated version of an STF intelligence structure. At the top of the structure is the judged conflict outcome—the likelihood of friendly forces successfully defending their area, that is, containing the attack (described below) and maintaining their viability as a combat force. The entire structure (not shown) consists of an intelligence section of hierarchical tiers below the operational outcomes portion of the structure depicted here. Operations officers from Ft. Leavenworth and intelligence officers from Ft. Huachuca participated in developing and defining factors; the operations officers from Ft. Leavenworth served as respondents in the three judgment experiments outlined in Figure F.1: estimating the degree of (1) Red attrition and (2) Red penetration that could result under different levels of the four factors constituting the lowest hierarchical tier; and estimating (3) the likelihood that Blue's defense would have been successful under different levels of Red penetration, Red attrition, and Blue attrition.

The combat backdrop to the three judgment experiments depicted in Figure F.1 is described below:

- Red has attacked in the U.S. corps-size battle area.
- Red units are modeled on Soviet organization structures.
- Both Red and Blue forces are composed of advanced systems (for example, enemy has tanks with reactive armor; precision guided advanced conventional munitions; advanced attack helicopters with target handoff capabilities and fire

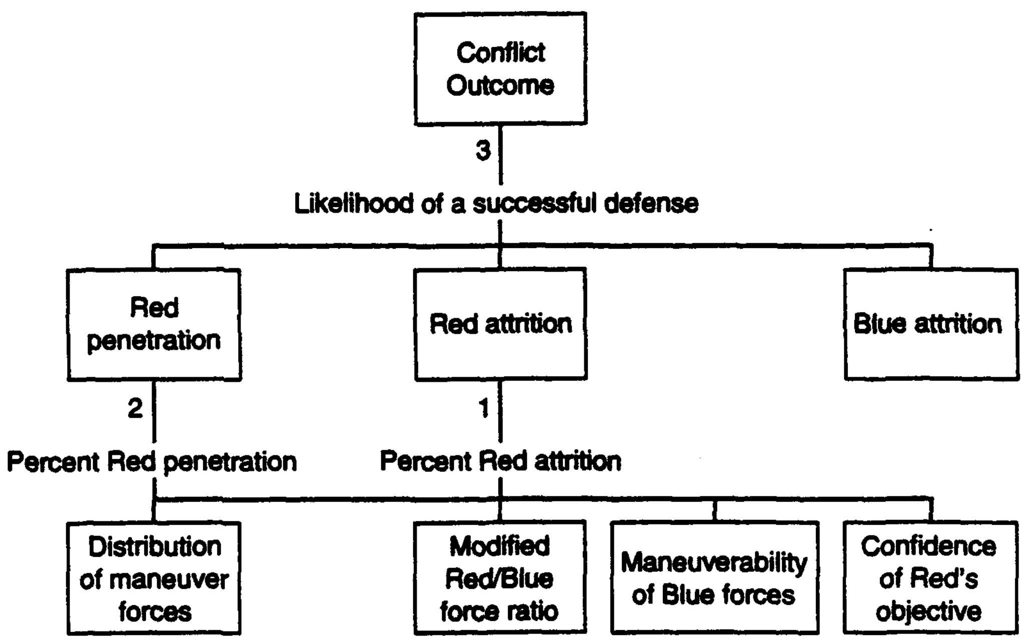

Figure F.1—Abbreviated STF Intelligence Structure

and forget missiles; NLOS close combat systems; quick fire targeting channels; advanced AD systems with advanced ECCMs).

- Time period: 4–5 days.

Table F.1 lists the factor definitions for factors shown in the lowest hierarchical tier of Figure F.1. These factor levels were manipulated in factorial designs to produce situations presented to operations officers for their judgment. Officers estimated the degree of Red attrition and Red penetration that would result in different situations described by different combinations of these factor levels.

Table F.2 lists the factor levels for factors constituting the middle hierarchical tier of Figure F.1. These factor levels were also manipulated in factorial designs to produce situations presented to operations officers for judgment. Officers estimated the likelihood that Blue forces would have successfully defended their position in different situations described by different combinations of these factor levels.

The 10 panels of data shown in Figures F.2 through F.5 were used to test among the unique predictions of different algebraic functions in the search for the appropriate STFs for the first, second, and third hierarchical functions, respectively, in Figure F.1.

Table F.1

Factor Definitions and Factor Levels for Lowest Hierarchical Tier

Factors	Factor Levels
<u>Initial distribution of maneuver forces</u> Distribution of the Blue and Red forces in the close (at the FLOT) and deep (>75 km from the FLOT) areas	Blue forces: close 2/3; deep 1/3 Red forces: close 1/3; deep 2/3 Blue forces: close 1/3; deep 2/3 Red forces: close 1/3; deep 2/3 Blue forces: close 2/3; deep 1/3 Red forces: close 2/3; deep 1/3 Blue forces: close 1/3; deep 2/3 Red forces: close 2/3; deep 1/3
<u>Modified Red:Blue force ratio</u> The force ratio that resulted from a modification of the initial force ratio because of the relative combat power of Red and Blue forces and the number of Red High-valued targets neutralized by Blue deep fires; it reflects the relative combat ability of the two forces	1:2, 1:1, 3:1
<u>Maneuverability of Blue maneuver forces</u> Likelihood that blue maneuver forces will be in the planned place in a prepared defense posture at the planned time	95%, 75%, 50%
<u>Red's operational objective</u> Confidence that Blue correctly knows the enemy's operational objective	90%, 50%, 10%

Table F.2

Factor Definitions and Factor Levels for Middle Hierarchical Tier

Factors	Factor Levels
<u>Red penetration (P)</u> The deepest point of enemy penetration at some point during the 4-5 day battle. (The battle did not end in a rout.)	0, 20 km, 50 km, 100 km
<u>Red attrition (R)</u> Percentage of red force attrited in the 4-5 day battle	20%, 30%, 40%, 50%
<u>Blue attrition (B)</u>	20%, 30%, 40%, 50%

In each panel of Figure F.2, the mean estimate of the percentage of Red attrition is plotted as a function of Red:Blue force ratio with a separate curve for each level of confidence of knowing Red's objective; a separate panel is for each level of Blue's maneuverability.

The fact that the positions of the three curves rise from Panel A-C indicates the judged increase on Red attrition that would be expected from Blue's maneuverability increase from 50 percent to 95 percent. The positive slopes of the curves in each panel illustrate the judged increase in Red attrition because of the change in force ratio from favoring Red 3:1 to favoring Blue 1:2. Separations between the curves indicate the effect of confidence in knowing Red's objective on Red attrition estimates, the greatest estimates being highest when confidence is highest (90 percent) in all three panels.

The curves in each panel depict divergent interactions: It makes less of a difference in how confident Blue is in knowing Red's objective when the force ratio is 3:1 than

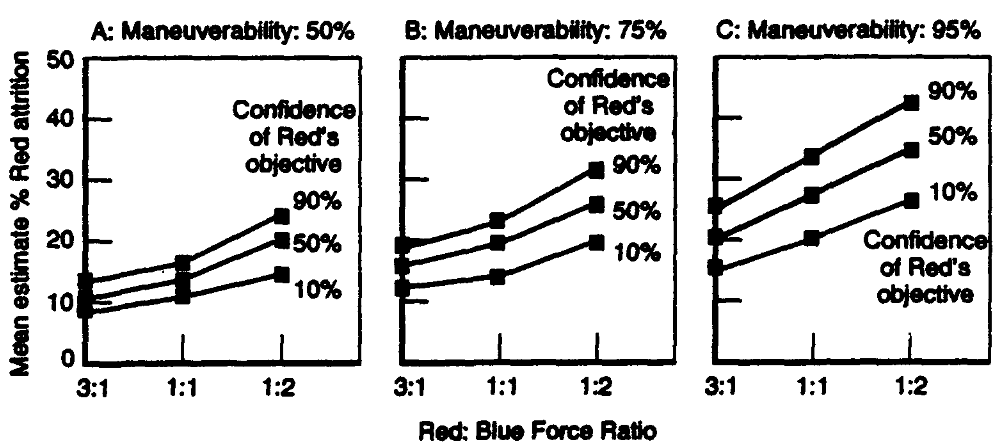

Figure F.2—Results of Experiment 2: Red Attrition

when the force ratio is either 1:1 or 1:2. This is the case in all three panels. Tradeoffs among factors can be seen by drawing horizontal lines through the curves. For example, about a 16 percent Red attrition is estimated in each of the following situations:

a. Blue maneuverability capability of 50 percent,
Force ratio of 1:1,
Confidence level of 10 percent;

b. Blue maneuverability capability of 75 percent,
Force ratio of 3:1,
Confidence level of 50 percent;

c. Blue maneuverability capability of 75 percent,
Force ratio of 1:1,
Confidence level of 50 percent.

Data in Figure F.3 are plotted similarly to those in Figure F.2 except that the mean estimate of Red penetration is on the y-axis. Red penetration was estimated to be greatest when Red outnumbered Blue, when Blue's confidence about knowing Red's objective was poor, and when Blue's maneuverability capability was poor. The difference in how far Red was estimated to penetrate Blue's area was much greater for a force ratio change from 1:1 to 3:1 than from 1:2 to 1:1, for all levels of confidence in knowing Red's objective. When Red's force ratio advantage was 3:1 and Blue's maneuverability capability decreased from 75 percent to 50 percent (Panels B and C), Red's penetration was estimated to increase 10–15 km. A 5 percent to 10 percent increase in Red's penetration was estimated for a decrease in Blue's maneuverability capability of 95 percent to 75 percent.

Again, overall divergent interactions were observed among all three variables. The divergent interaction between initial force ratio and confidence in knowing Red's objective can be seen by comparing the vertical distances between the bottom and top curves at a Red/Blue force ratio of 1:2 and 3:1 on the x-axis in all three panels. In all three panels, the vertical distance is less at a Red:Blue force ratio of 1:2 than 3:1, indicating that confidence in knowing Red's objective made *less* of a difference when

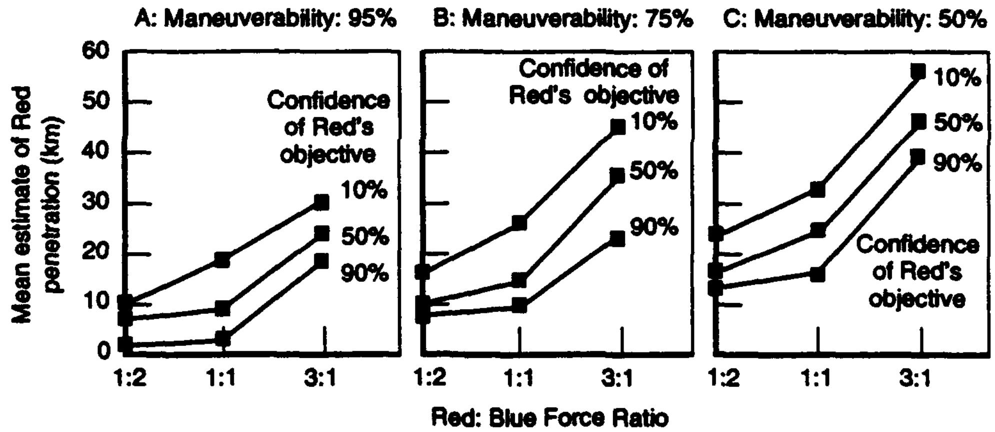

Figure F.3—Results of Experiment 1: Red Penetration

Blue had a 2:1 force-ratio advantage than when Red had a 3:1 force-ratio advantage. Again, tradeoffs among the factors force ratio and confidence in knowing Red's objective can be seen by drawing horizontal lines through the curves in each panel. For example, a 20 km Red penetration was estimated for a 95 percent Blue maneuverability capability (Figure F.3A) when the Red:Blue force ratio was 3:1 with a confidence of knowing Red's objective of 90 percent, as well as for the situation where the confidence level was reduced to 10 percent, but the force ratio was 1:1. A penetration of around 23 km is estimated for a Blue maneuverability capability of 50 percent (Figure F.3C), a force ratio of 1:2, and a confidence level of 10 percent, or a force ratio of 1:1 and a confidence level of 50 percent. Additional interesting tradeoffs can be seen by scrutinizing the data.

Mean estimate of likelihood of a successful defense is plotted on the y-axis as a function of percentage Red attrition on the x-axis; a separate curve is plotted for each level of Blue attrition and a separate panel is for each level of degree of Red penetration. (See Figures F.4 and F.5.) As can be seen from the different positioning of the curves from Panels A–D, as the degree of Red penetration decreases from 100 km to 0 km, the likelihood of a successful defense increases, as would be expected,and has an estimate of about 96 percent when Red penetration is 0, Blue attrition is low (10 percent), and Red attrition is high (50 percent) (see the top point in Panel D). Separations between the curves in Panels A–D illustrate the effect of Blue attrition on estimates of a successful defense; the slopes of the curves illustrate the effect of Red attrition.

The curves in Panels A–C are essentially parallel, indicating that the effect of the level of Blue attrition is independent of the level of Red attrition. The interaction in Panel D, however, indicates that it made a greater difference in how much Blue attrition was suffered when Red attrition was low than when Red attrition was high (compare the vertical distance between the top and bottom curves at a Red attrition of 20 percent and 50 percent on the x-axis in Panel D).

Tradeoffs among Red and Blue attrition in the likelihood of a successful defense can be seen by drawing horizontal lines through the curves in each panel. For example, when there was no Red penetration (Panel D), a 20 percent Red attrition and 30 percent Blue attrition had about the same likelihood of a successful defense (about 60 percent) as a 50 percent Red attrition and 40 percent Blue attrition. From Panel C, about a 60 percent likelihood of a successful defense would also be expected for Red/Blue attrition levels of 30/10, 40/30, and 50/40. When Red penetration is 100 percent (Panel A), the Red/Blue attrition ratio has to reach 50/10 before the likelihood of a successful defense reaches the 65 percent level.

The data structure shown in the ten panels (Figures F.2, F.3, and F.4) made it possible to reject many algebraic models as appropriate STFs for the three hierarchical junctures shown in Figure F.1. In particular, additive and averaging models were ruled out, as were simple multiplicative combinations of factors. The rationale and procedures underlying testing algebraic models can be found in Anderson (1981), Birnbaum (1974), Birnbaum and Veit (1974a, 1974b), Krantz and Tversky (1971), and Veit (1978). For more information on the STF approach to complex systems analyses see Veit and Callero (1982).

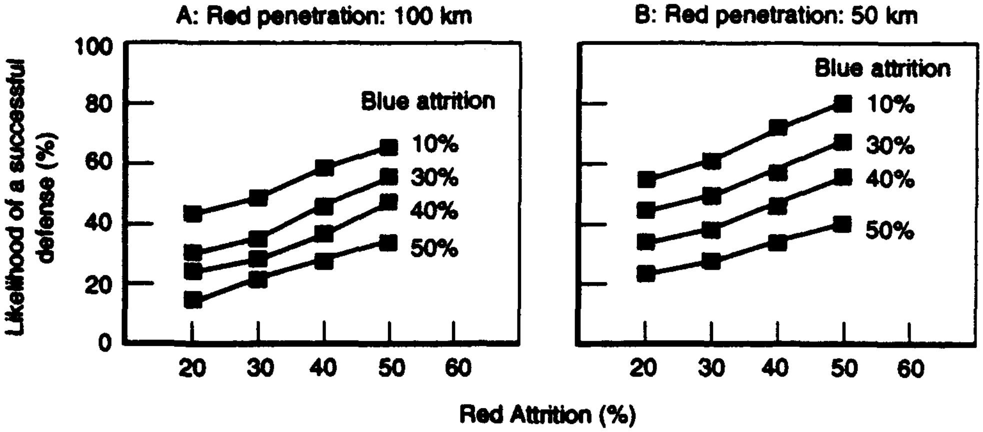

Figure F.4—STF Example: Battle Outcome Cases 1 and 2

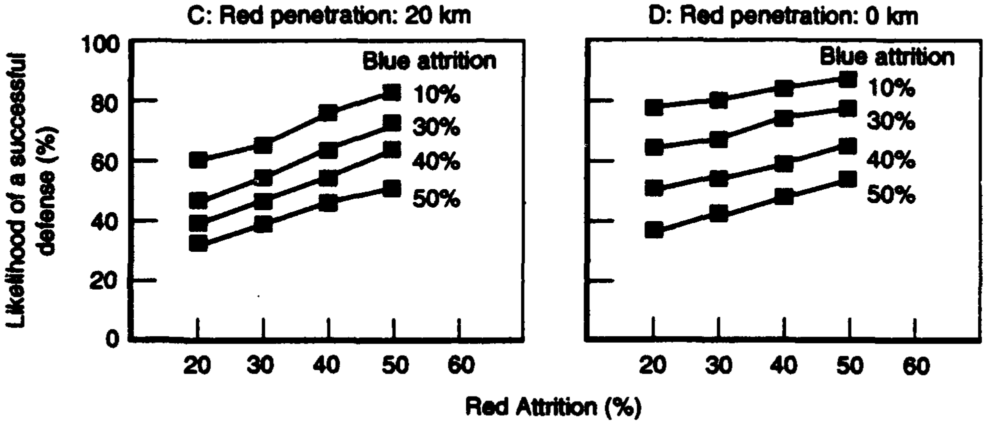

Figure F.5—Results of Experiment 3: Likelihood of a Successful Defense

A simple range model accounted for each set of data. Thus, the STF for all three hierarchical junctures can be written as a simple averaging model with a special effect because of the range of capabilities or events that describe a situation. The model for juncture three in Figure F.1 can be written:

$$D = a\left[\frac{w_0 s_0 + w_{BA} s_{BA(i)} + w_{RA} s_{RA(j)} + w_P s_{P(k)}}{w_0 + w_{BA} + w_P} + \omega\,(s_{MAX} - s_{MIN})\right] + b$$

where D = judged likelihood of a successful defense, w_0 and s_0 are the weight and scale value associated with the initial impression (what the estimate would have been in the absence of specific information); w_{BA}, w_{RA}, and w_P are the weights associated with Blue attrition (BA), Red attrition (RA), and Red penetration (P), respectively; $s_{BA(i)}$, $s_{RA(j)}$, and $s_{P(k)}$ are the subjective scale values associated with the levels of BA, RA, and P, respectively; s_{MAX} and s_{MIN} are the maximum and minimum valued pieces of information in a particular judged situation; ω is the weighting factor of the range term; and a and b are constants.

All the parameters are estimated from the data; weights and scale values do not have to be known in advance to test among theories. Once the judgment theory (STF) and its parameters are known, the STF model can be used in standalone analyses or embedded in a simulation (e.g., the OPVIEW model).

Algebraic modeling procedures illustrated here allow for judgment theories in the form of algebraic models to be hypothesized and rejected when incorrect. The notion of rejecting incorrect theories is an important feature of any validation process.

Appendix G

VERIFICATION, VALIDATION, AND ACCREDITATION PLAN

The Department of Defense requires that all models to be used for studies be verified, validated, and accredited (V, V, and A). The OPVIEW project was not intended to produce an applications model that would be fully validated or accredited. Instead, it produced prototype models that could be used to demonstrate the methodology's potential applications. Nevertheless, when the prototypes reach a stage in their development at which they are ready for application, the Army may want to verify and validate or accredit them.

THE CHALLENGE FOR VERIFICATION AND VALIDATION

The OPVIEW methodology enables the analyst to examine and study interactions between intelligence systems, decisionmaking, and operations outcomes to illustrate how the intelligence systems and procedures contribute to the overall outcomes of combat or noncombat operations. The methodology is therefore heavily focused on behavior and judgment, rather than engineering, although it takes into account the underlying physical phenomena of sensor capabilities and their operating environment. We understand that no combat model above the system level can be validated, but such a model can be accredited according to Army standards.

VERIFICATION, VALIDATION, AND ACCREDITATION PLAN

As a research project, OPVIEW differed somewhat from the approach described for Army Model Life Cycle Stages in the October 1989 memorandum published by the Deputy Under Secretary of the Army for Operations Research. An illustration of those stages is in Table G.1. The research for this project focused on a methodology that can best be described as knowledge-based simulation technology.

A typical software engineering approach to model development would take the tasks and requirements specified by the sponsor and develop a software program to meet those requirements; the sponsor would have a sequential V, V, and A process to match the software engineering process. However, in the case of the OPVIEW models, RAND performed research to determine a procedure for measuring the operational value of intelligence and electronic warfare in operational outcome terms, then performed the function of defining what tasks and requirements were necessary to be encoded in a production model.

Table G.1

Model Life Cycle Stages

1988	1989	1990	1991	1992–1993
Model Concept	Requirement Definitions	Preliminary Design	Detailed Design	Coding
Entities represented Purpose General approach	Functional Operational Interfaces Performance	Architecture defined Technical approach described	Refined architectures Described embedded algorithms	Testing
	Initiate V, V, & A plan	Review architectural and theoretic foundations	Review	Postdeployment software support plans
	Establish acceptability criteria	Review types and formats of data for appropriateness and availability	Threat doctrine and tactics Architecture Theoretic approach Embedded algorithms Underlying assumptions	

NOTE: Stages defined in Army DUSA-OR Memo, October 1989. Timelines reflect hypothetical schedule for a normal system engineering approach to software programs.

Now that RAND has completed the research on the measures, this appendix outlines the tasks and requirements for a production model. Our method of demonstrating the concepts is to illustrate them in the prototype OPVIEW models.

Acquire (target) The process of detecting the presence and location of a target in sufficient detail for identification or to permit the effective employment of weapons.

Area coverage The physical area on the ground from which a given type sensor can gather data or information or otherwise perform intelligence operations, e.g., direction finding, jamming.

***Array** A list of items, constructed by placing items in adjacent locations in the computer's memory. This is easier to use than a linked list but makes it difficult or impossible to add, delete, or rearrange items or to extend the list beyond a predetermined length.

Battle damage assessment The process of collecting and analyzing information about a threat entity that has recently been attacked to determine how much and what type of damage was done to it.

Classification A threat entity's definition, e.g., an armor unit.

Classify The determination of a particular type or class of threat entity or other category of military significance, e.g., a tank regiment.

Collection system A single component or a group of active or passive components used to detect, measure, compare, or otherwise gather data about physical signatures of one or more threat entities, or other indicators associated with ground or airborne assets, facilities, military or civilian activities (e.g., their movement, physical shape, emissions in the electromagnetic spectrum, effluents, or other phenomena).

Communications link A way to transfer data or information between two nodes, typically, a radio path.

Communications path A way to communicate between two or more nodes in a communications network.

Control data link A data link used to control a platform, collection system, onboard processor, or other operations of the various components of a collection system.

[1]Computer terms are designated with an asterisk.

Controller A person or group of individuals participating together, directing the operations of a collection system, including its platform and other on-board operations, and determining where and how to disseminate its data/information.

Coverage The ability to make observations with sensors or other collection means. Usually refers to areas on the ground that are "observed" by one or more sensors.

Coverage depth The physical distance, laterally across the Forward Line of Own Troops (FLOT), or other line of demarcation, within the area of interest or operations, or general battle area in a region of operations, that a sensor system, including its platform, can cover over a given period of time. For space and aerial systems, includes swath width and paths (or spot diameter), and revisit periodicity.

Coverage width The physical distance, forward of the FLOT, or other line of demarcation, within the area of interest or operations, or general conflict area in a region of operations, that a sensor system, including its platform, can cover within a given period of time. For space and aerial systems, includes swath width and paths (or spot diameter), and revisit periodicity.

Conditional Collection Probability Factor (CCPF) Modified CPFs according to the environmental and operational conditions of a given region, i.e., topography, weather, and passive and active countermeasures. CCPFs are used in both the value-added scoring process and dynamic operations simulations to quantify system performance.

Collection Probability Factor (CPF) A factor that measures the ability of intelligence collection systems to physically collect data about commanders' information needs, decomposed according to a common standard to detect, locate (generally or precisely), classify, identify, track, acquire, or assess the combat status of one or more threat entities.

Data link A communications link used to exchange data between two or more nodes.

Detectable signatures One or more unique detectable or observable characteristics of a threat entity, or threat entity grouping, that can be used to derive data or information about a threat entity's presence, type classification, configuration, specified activity, location, identity, or status. Examples are physical shapes, organizational patterns, component separation, size, quantity, association with subelements or components, and electromagnetic emission frequency domain, operating patterns, and schema.

Detection The discovery by any means of the presence of a person, object, or phenomenon of potential military significance. The perception of an object's presence (i.e., threat entity) of possible military interest but unconfirmed by recognition.

Direction A vector of movement, e.g., north, east, south, west.

General location accuracy Detection location accuracy that is suitable for indications and warning, situation development, and target development.

Ground support module A stationary or mobile ground facility that can receive raw or processed data from one or more collection systems and disseminate it to users

elsewhere in a collection system's architecture, typically to a consumer or to an intelligence production and dissemination center.

Identify Discrimination between objects within a particular type or class, or the specific attributes of an identifiable military unit or other classifier, e.g., the 1st tank regiment.

Intelligence collection system Any combination of equipment, software, and operator personnel for performing intelligence/information collection or ESM activities, including detectors, on-board processor, human operators and analysts, data or information dissemination means, and associated protection and position navigation capabilities.

Intelligence production and dissemination center A stationary or mobile ground or airborne facility that can receive raw or processed data, or information, from one or more collection systems of the same or dissimilar type, process it with other data, collate with previously collected data or information from internal or external sources, perform analysis, produce intelligence, and disseminate information or intelligence products to users employing standard formats.

***Linked list** A list of items constructed so that each item in the list indicates which item is next. This arrangement allows items to be easily inserted or removed from any place on the list, and allows the list to be extended to arbitrary lengths.

Locate generally An area, position, or site occupied or available for occupancy or marked by some distinguishing feature, e.g., an assembly area.

Locate precisely A specific position, site, or object whose coordinates are known and reportable, for targeting or other action.

Measures of collection results Measures of intelligence/information: timeliness, relevance to mission and command level, accuracy, adequacy, comprehensiveness (plausibility, understandability, language interpretation/translation, decryption).

Measures of effectiveness (MOEs) Modified IEW/TA system performance according to the operational setting, employment doctrine, and strategy constraints, plus the effects of weather, topography, and countermeasures; revised measures of performance (MOPs) characteristics for a given system when it is deployed, since system effectiveness then is usually less than the full capabilities of the system design; political and operational constraints, effects of weather and terrain, and enemy countermeasures, *inter alia*, all serve to limit the potential or actual performance of any system. MOEs are measured in relation to the constraints that describe the reduced performance of each system. MOEs are also measured in relation to the command-level decisions required to plan and accomplish a unit's mission. Thus, they are the integrating link between purely physical phenomena, situation-dependent factors, and command decisionmaking.

Measures of (operational) results The increased opportunity for each side to accomplish its mission in more favorable or less unfavorable situations over time, where favorable is defined as desirable operational outcomes measured for *combat operations* by such achievements as control of the initiative, e.g. attack, defend; attrition inflicted on each side; change in control of territory, e.g., FLOT movement; relative posture of each side after a battle, i.e., change in force ratio;

the ability to avoid being surprised or deceived, and to inflict surprise or deception. For *noncombat* operations, for example, keeping opposing forces separated beyond the range of their weapons, increasing or decreasing the number of serious incidents, over time, compared with a baseline. Other types of results of either combat or noncombat operations may also be compared.

Measures of performance (MOPs) Related to system-level phenomena obtained from system specification publications, e.g., Mission Essential Needs Statement (MENS) and Operational Requirement Documents (ORDs), system technical descriptions, and technical manuals. They are parametric characteristics of IEW/TA system design performance, e.g., platform, sensor, jammer characteristics.

Measures of utility (MOUs) Measured ability of one IEW/TA system or a mix in a given operational setting to support a decision within the chosen time period for analysis. Utility is measured by the collected information's timeliness, accuracy, adequacy, and understandability, plus tradeoffs among these qualities.

Measures of value The summarized values attributed to IEW/TA, or other systems, that are derived from sufficient and often extensive sensitivity analyses of the measures of results. In the most aggregated form, value can be judged by making a change in IEW/TA capabilities to one or both sides and then counting the increase or decrease in the number and mix of potential, simulated combat or noncombat situations that are determined to be favorable to one side or the other.

Minimum essential package A group of collection, production, and intelligence dissemination systems that can function together to support operational requirements in one or more conflict regions. A package contains the minimum number and types of systems, and their quantities, to meet stated operational requirements.

Mission speed The average rate of speed at which a collection/ESM platform operates; for aerial systems includes fly-out, on-station collection, and fly-back times.

Mission time The duration of an operational mission assigned to a specific collection or ESM platform and system; for aerial systems includes fly-out, on-station collection, and fly-back times.

Node A termination or intermediate point in a communications network, usually where data or information is collected, recorded, entered in a computer terminal, processed, or disseminated.

On-board processor One or more components of a collection system, including its software, that is used to transform results of detections into structured data, aggregated data, or other usable forms of data or information as an intelligence product.

Operations vignettes Derived from either approved or candidate combat or noncombat scenarios. They depict the initial phase and planned subsequent phases of engagements between opposing forces and are intended as tools for dynamic simulations to help illustrate important dynamics and key results. They include such information as Red and Blue force descriptions, region, theater, areas of operations, major terrain features and obstacles, weather conditions, types of active and passive countermeasures, day of the conflict and campaign duration, regional objectives, strategies, missions, attack/defense organizations, concept of

operations, schemes of maneuver, and dispositions of opposing forces plus their support. They provide modeling structures and data for the analyst to enter as operational parameters in such models as the OPVIEW dynamic model.

Platform A space, aerial, ground-mobile vehicle, or stationary platform that carries one or more collection or ESM systems. Single or multiple platforms may be used to carry any or all components of a total system, e.g., detector, on-board processor, human operators and analysts, software, data or information-dissemination transmitters, on-board protection capabilities, and position navigation (POSNAV) means or links to an external POSNAV system.

Platform on-station time The amount of time a platform spends adjacent to, in, or above the assigned mission area, during a single mission or sortie, when it is assigned to a given area while engaged in collection or ESM operations; for moving space systems, a single pass over a designated area; for geostationary space systems, continuous for the duration of assignment to the area; for aerial systems, a single mission or sortie; for ground systems, continuous for the duration of assignment or tasking to the area.

Platform operating altitude The elevation (average height above ground) a space or aerial platform operates at when it is engaged in collection or ESM activities. Altitude may also be expressed as the typical or standard operating altitude within a range of maximum and minimum altitudes. The operating altitude may be governed by platform vulnerability factors, e.g., to avoid certain classes of enemy air defense weapons.

Platform operating range The distance a platform can travel, over time, during a single collection or ESM operation or mission (i.e., for aerial systems, the lateral and in-depth area dimensions above the ground; for space systems, the ground area swath width and length coverage per unit time; for ground systems, the ground area fan or spot coverage per unit time).

Platform operating speed The rate of movement a platform travels when it is engaged in collection or ESM operations.

Platform performance factors Quantified measures that pertain to the performance capabilities of various types of collection and ESM platforms that collectively, when integrated across all the important ones, define a system's ability to cover a given intelligence target area.

Postattack operational assessment The process of collecting information about a threat entity that has recently been attacked to determine its residual operational capability.

Poststrike assessment Same as battle damage assessment.

Preferred package A group of collection, production, and intelligence dissemination systems that can function together to support operational requirements in one or more conflict regions. This package is larger than a minimum essential package in terms of system types or their quantities to meet stated operational requirements, according to an analyst's criteria for robustness, survivability, and follow-on operational contingencies.

Processed data Data partially or completely transformed (e.g., structured, formatted, aggregated, combined with other data) into information to use in producing an intelligence product.

Processed intelligence results Data received from one or more collection systems combined into an integrated intelligence product.

Raw data Unprocessed data, typically in digital form, derived from the output of a collection system.

Revisit time Elapsed time between sensor collection or ESM events by the same system.

Sensor A technical means for collecting useful data or information about a threat entity.

Sensor category Established groupings of sensor technical types according to intelligence functions, e.g., COMINT, ELINT, HUMINT, IMINT, MASINT.

Sensor factors Quantified measures pertaining to the performance capabilities of various types of sensors, or detectors, that either singly or in conjunction with others provide data or information about a threat entity's presence, type classification, configuration, specified activity, location, identity, or status.

Sensor type A particular technological means, within a given sensor category, used for intelligence collection. Within each sensor category there can be more than one sensor type, e.g., under the IMINT category there currently exists photo, TV imagery, LLLTV imagery, IR, IR thermal imagery, SAR, and MTI types.

Standoff range The distance behind the FLOT, or other designated limit, e.g., a phaseline, that a platform will not intentionally go beyond when engaged in collection or ESM operations. Applies only to ground and aerial platforms, not space platforms.

System control module A stationary or mobile ground or airborne facility that is used to control the operations of one or more collection systems.

Threat entity One or more identifiable enemy units, weapons, or other major systems that intelligence collection systems should be capable of detecting, locating, classifying, tracking, acquiring, or assessing the status of, e.g., armored division, tank regiment, SCUD launcher.

Time measure (for intelligence collection, production, and dissemination) The amount of time required to pass data or information through a network of paths and nodes in a specified architecture, referred to as total time. The total throughput time for a single network design consisting of a set of two nodes connected by a single uninterrupted path between a collector and user is measured as 1.0. All other network designs that contribute time degradation factors are related to this standard and fall between 0 and 1.0.

Track A record of the successive positions (over time) of a moving object. The projection on the surface of the earth of the path of a vehicle, the direction of which path is usually expressed in degrees from north (true, magnetic, or grid).

Unit size, category General identification of a threat entity type according to its size related to standard unit sizes, e.g., a regiment.

Unit type Specific identification of a threat entity according to its designed or intended function, e.g., a tank regiment.

User or consumer (of military intelligence products) A person or a group of individuals (typically, a commander or his staff at an operating command) participating together in a common operational activity, e.g., warfighting, decisionmaking, planning, assessing results of operations, or performing other operational activities. These activities may include (for combat operations) maneuvering a force or firing a weapon. For noncombat operations, to protect a group of individuals (e.g., civilian, military, government leaders) or protect/shield specific physical assets (e.g., banks, dams, water supply or power stations, government facilities, ports, airfields).

Value added The potential contribution to operations of a single system, or group of systems, that can perform a given intelligence-collection or production function to enable or support a specified task or series of tasks, whose output is compared with either additional units of the same system or with a different type of system that can perform the same function.

Vulnerability An expected measure, expressed as a probability factor, for each collection or ESM system, platform, or network's interruption resulting from possible enemy operations or mechanical or operator failure.

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